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Developing Sitka Spruce Populations for Resistance to the White Pine Weevil

Summary of Research and Breeding Program

2009

BRITISH COLUMBIA
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Ministry of Forests and Range
Forest Science Program

050

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John N. King and René I. Alfaro

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ABSTRACT

This publication reports on the results of over two decades of research in the Sitka Spruce Breeding Program. The objective of the Sitka spruce (*Picea sitchensis* [Bong.] Carr.) breeding program is to develop, propagate, and deploy genotypes with robust resistance to the white pine weevil (*Pissodes strobi* Peck). The program is based on research that has been conducted on the extent and nature of genetic resistance in Sitka spruce populations in British Columbia. This research has international stature and provides a successful model for incorporating the results of research on natural genetic resistance to insect pests into applied breeding programs and proactive forest management.

EXECUTIVE SUMMARY

The Sitka spruce breeding program has been an ongoing cooperative effort between the Research Branch of the B.C. Forest Service, the Pacific Forestry Centre, and B.C. universities. By building on prior knowledge and developing new research installations, our goal is to enable managers to restore the Sitka spruce component of the regenerated forests of coastal British Columbia. The revival of this fast-growing and valuable species will benefit the forest industry, forest-dependent communities, and the provincial economy. It will also support the restoration of an important component of our coastal forest ecosystems.

To date, research activities have included studies of individual trees, families, and source populations that express weevil resistance; the development of methods to screen for resistance; and efforts to identify the physiological and genetic controls of these resistance mechanisms. From the late 1970s to the present, close to 100,000 trees have been established in nearly 100 experimental plots (EPs) (Appendix 1). Detailed studies of insect outbreaks and population dynamics have been conducted in these plots, the results of which may provide useful guidelines beyond just the spruce/weevil system. An evaluation of hazard rating and seed transfer has also been part of this program. When final results are available, they will be incorporated into existing best practices guidelines for forest management in Sitka spruce habitat. This report details the historic development and ongoing activities of the Sitka spruce breeding program.

Key results of the program include the following:

1. development of a methodology for rapid screening of weevil resistance using artificial infestations (Alfaro et al. 2008);
2. development of methods to quantify resistance based on statistically testable data (King et al. 2004);
3. screening of many populations, families, and individuals to identify those with durable resistance (this report);

4. propagation of the best individuals and families into seed orchards that are now producing seeds with a high degree of resistance (this report);
5. indications that the basis for the resistance is very likely a complex interaction of genotype and environment, manifested by more than one resistance mechanism. Factors in this resistance include density of sclereid cells and resin canals. In some genotypes, a very strong resistance was observed (Alfaro et al. 2002); and
6. indications that resistance is stable, viable over a wide area, and appears durable over the phase of susceptibility to attack. New guidelines for deploying resistant Sitka spruce were proposed as a means of encouraging foresters to use Sitka spruce more often and in higher proportions on suitable sites in the Coast Forest Region (following Heppner and Turner 2006).

ACKNOWLEDGEMENTS

This report represents over two decades of research, mainly by the B.C. Ministry of Forests and Range (MFR), Research Branch, initially spearheaded by Cheng Ying; and the Canadian Forest Service (CFS). Key support was provided by Simon Fraser University, particularly John Borden and his associates and students, and co-operators in the British Columbia forest industry, especially John Barker and Annette van Niejenhuis of Western Forest Products Ltd.

Our field staff deserve the lion's share of thanks. From the B.C. Ministry of Forests and Range: Charlie Cartwright, Doug Ashbee, and David Ponsford. From the Canadian Forest Service: Lara van Akker and George Brown. Without the dedication of these people none of these results could have been achieved. Our thanks to the following reviewers: Barry Jaquish (MFR), Don Heppner (MFR), Peter Ott (MFR), Jodie Krakowski (MFR), Gaëtan Daoust (CFS), and Robert Lavallée (CFS). We would like to acknowledge Moraia Grau and Jodie Krakowski for all their help in editing this report and the managers at MFR (Alvin Yanchuk in particular) and the CFS for their continued support for this program. We would also like to thank the Forest Genetics Council for funding the prepress work of this publication.

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Sitka spruce (*Picea sitchensis* [Bong.] Carr.) is an integral component of the coastal rainforest of western North America; however, over the last three decades its economic importance has declined because of its susceptibility to insect damage. Sitka spruce has vigorous growth and excellent wood properties. The value of this versatile wood is reflected by its historically relatively high stumpage rate in British Columbia. This strong, light wood was preferred for specialty products, such as components of the de Havilland Mosquito bomber and the Hughes Spruce Goose aircraft, and it is still prized for guitar and piano manufacturing. In addition to its economic value, Sitka spruce is a key aesthetic element of the tall timber forests and the biodiversity of the west coast of North America.

Despite its historical and economic value in British Columbia and the U.S. Pacific Northwest, Sitka spruce has not been a favoured species for reforestation in many sites where it naturally occurs. This is because it is highly susceptible to terminal leader damage by the white pine or terminal weevil (*Pissodes strobi* Peck) in drier, warm habitats, which comprise a high weevil hazard. Although this insect does not directly kill the tree, damage causes extreme stem form defects (Alfaro 1989), and in severe cases will cause plantation failures (Figure 1). Sitka spruce plantings in British Columbia have been reduced from a historic level of 10 million to fewer than one million trees annually (B.C. Ministry of Forests and Range 2008). Planting is now limited mainly to the Queen Charlotte Islands, which have no weevils, and to low weevil hazard areas on the mainland and Vancouver Island. Sitka spruce planting is minimal in Oregon and Washington due to the weevil's impact.

FIGURE 1 *Severe attack and plantation failure at the Green Timbers plantation in Surrey, B.C. This site was planted with Queen Charlotte Islands origin material, which later proved to be highly susceptible to the white pine weevil.*

Sitka spruce is an important exotic forest plantation species outside of its native range, where there are no terminal weevils. In England, Scotland,[1] and Ireland, over 50 million Sitka spruce are planted annually, and there is some interest in planting the species in Denmark and Norway (Hermann 1987; Samuel et al. 2007).

The white pine weevil is a native insect that ranges across Canada and the northern United States. In the east, it is a major pest of eastern white pine (*Pinus strobus* L.) and the exotic Norway spruce (*Picea abies* [L.] Karst) (Daoust and Mottet 2006), but in the west it mainly attacks native spruce species, particularly Sitka spruce. Adult weevils overwinter on the forest floor or within the crown foliage. After mating in the spring, the females lay their eggs under the bark, usually near the top of the previous year's terminal shoot. Through the summer the larvae mine downward, consuming the phloem and severing the cambial layer in the elongating terminal shoot. The terminal shoot then typically wilts and dies. Attacked trees may recover apical leader growth after a lateral shoot turns upward in a process that may take 1 to several years. New leaders may also be attacked in subsequent years. The result is that attacked trees have diminished height and volume growth, and a crooked, bushy form (Figure 2). In severe infestations, attacked trees attain only a shrubby form. Silvicultural control techniques such as spacing, shading, clipping, insecticide use, or biological control are not very effective or practical on their own (Alfaro and Omule 1990; Fraser and Szeto 1994; Hulme 1994; McLean 1994; Rankin and Lewis 1994; Taylor et al. 1996).

FIGURE 2 *Severe and repeated attack leads to prominent bushy growth habit (Knight Inlet, B.C.).*

1 www.forestry.gov.uk/pdf/nursery2007finaldoc.pdf/sFILE/nursery2007finaldoc.pdf.

The discovery of genetic resistance to the white pine weevil likely offers the best chance of restoring Sitka spruce within the coastal forest management system. Sitka spruce genotypes that were clearly resistant to weevil damage were first noted in British Columbia in the early 1940s at the Green Timbers plantation in Surrey (Figure 1), where five trees escaped an extreme attack that destroyed a 10-ha Sitka spruce plantation (Alfaro 1982, 1995; Alfaro and Wegwitz 1994). Populations and individuals differ in their susceptibility to weevil attack. Mitchell et al. (1990) noticed that natural hybrids of Sitka and white spruce (*Picea glauca* [Moench] Voss) showed markedly less attack than pure Sitka spruce, although hybrid growth rates varied greatly. F_1 hybrids, the offspring of controlled crosses between one Sitka and one white spruce parent, have been tested by the British Forest Commission.[2] Although early growth was sometimes promising, long-term performance could not match that of pure Sitka spruce. Lutz spruce (the name often used for the natural hybrid) was grown commercially for a limited time in Washington and Oregon, but its poor overall growth performance made it an unattractive option.[3]

Early provenance trials established by the B.C. Forest Service (BCFS), under the auspices of IUFRO (International Union of Forest Research Organizations) (Fletcher 1976; O'Driscoll 1976; Illingworth 1980), showed indications of population-level weevil resistance (Ying 1991). Results have shown a marked and durable resistance to the weevil that differs across provenances (Alfaro and Ying 1990; Ying 1991; King 1994; Ying and Ebata 1994). Resistant provenances consistently originated from the natural hybridization zone where the ranges of Sitka and white spruce overlap in north coastal British Columbia and in two provenance sources of pure Sitka spruce: one from eastern Vancouver Island (Big Qualicum, [BQ]), and the other from the lower Fraser Valley (Haney) (Figure 3). Big Qualicum and Haney are within the high weevil hazard area associated with the relatively dry Coastal Douglas-Fir biogeoclimatic zone and drier units of the Coastal Western Hemlock zone.[4] In areas with hot, dry summers, weevils rapidly meet critical heat sums, and trees suffer drought stress. Summer heat sums and potential vapour pressure deficit regimes delineate hazard zones, which are important for weevil damage assessment and control (McMullen 1976; Spittlehouse et al. 1994).

The results of provenance trials (Ying 1991) formed the basis of a weevil screening program that was used to broaden the base of genotypes and mechanisms of resistance essential for selection and breeding for resistance to the weevil. The first screening program was conducted by Cheng C. Ying as part of his mandate as provenance forester. He sought to test the repeatability of the resistance found in the IUFRO trials and to determine if resistance was widely distributed within the areas of origin around the Haney and Big Qualicum populations. Trees were selected from the IUFRO trials or in stands close to these two resistant sources, and clonal trials using juvenile

2 S.J. Lee, Forest Commission, Edinburgh, Scotland, pers. comm.
3 M. Bordelon, Oreg. Dep. For., pers. comm.
4 For detailed information on the biogeoclimatic ecological classification (BEC) system used to describe and classify ecosystems in British Columbia, and descriptions of the climate, distributions, and ecological communities characterizing these zones, see BEC Web, the online resource hosted by the B.C. Ministry of Forests and Range at www.for.gov.bc.ca/hre/becweb.

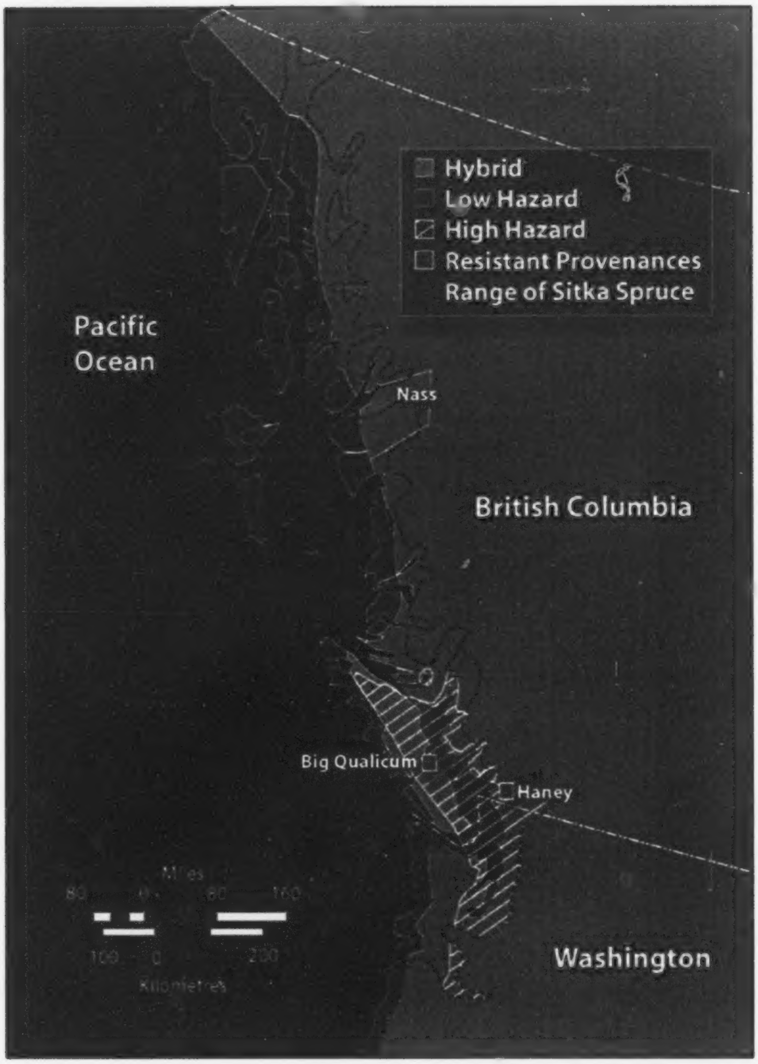

FIGURE 3 *Sitka spruce weevil hazard zones (Ying 1991) showing the early defined provenances for resistance: hybrid zone, Big Qualicum, and Haney. The hybrid zone delineates the Nass and Skeena River valleys where Sitka and white spruce hybridize.*

cuttings and grafts from older trees were established. The second series of research installations was initiated by John N. King as part of the Sitka spruce breeding program. Additional open-pollinated (OP) families were selected from a wider range of populations from ecologically similar areas to those where the two resistant sources originated. This was primarily in the high-hazard zone of southwestern British Columbia but also extended to similar areas in Washington and Oregon under the hypothesis that the observed

phenotypic resistance would be widely distributed within this zone due to natural selection pressure from high weevil attack levels (King 1994). Most of these clonal and OP family trials have now been screened for weevil resistance. Artificial weevil infestations of experimental trials have allowed all of the selected populations to be screened very quickly; due to relatively uniform weevil pressure across a test site, resistance screening can be completed approximately 5 years after establishment (Alfaro et al. 2001, 2008; King and Alfaro 2001).

This report synthesizes the achievements to date of research on Sitka spruce breeding for terminal weevil resistance in British Columbia. It includes a review of weevil resistance information for provenance trials that are now 30 years old and which have endured many years of intensive and repeated attack and assessment. Screening results from the clonal and OP family trials are also reported. A Sitka spruce breeding program was established based on these results, and an F_1 population has been established as an experimental population to study the mechanisms of resistance in detail and determine their inheritance. The breeding program, current knowledge of weevil resistance mechanisms, and a resistance rating system for Sitka spruce are described in this report. In addition, breeding and assessment programs for Sitka spruce growth and adaptability on the Queen Charlotte Islands (QCI) and in the Nass/Skeena hybrid zone are discussed. This report also shows how in-depth monitoring of weevil infestations provides insights into host responses and defences, and can provide insights into other insect epidemics, including that of the mountain pine beetle. Finally, this report provides deployment guidelines for new resistant material that is now available from provincial seed orchards.

2 DESCRIPTION OF WEEVIL RESISTANCE PROGRAMS

2.1 Provenance Program

British Columbia has a long history of provenance testing for commercial forestry species. The infrastructure dedicated to testing Sitka spruce, founded upon the IUFRO collection made by Alan Fletcher of the U.K. Forestry Commission, is second only to the large-scale province-wide testing of lodgepole pine (*Pinus contorta* var. *latifolia* Dougl. ex Loud.) (Illingworth 1978).

2.1.1 IUFRO series (EP 702.03, 702.04, 702.05) The IUFRO Sitka spruce provenance experiments (EP 702.04 and 702.05) are described in detail by Fletcher (1976), O'Driscoll (1976), and Ying (1991, 1997) (Appendix 1A). To summarize: 14 provenances were tested across eight sites with 10 provenances planted at each site. The tested provenances cover the species' main coastal range from southeast Alaska to southern Oregon and inland to the Sitka–white spruce hybridization zone around the Nass and Skeena Rivers of north coastal British Columbia. These trials were planted in a randomized complete block design with nine replications of nine-tree plots spaced at 3 × 3 m. Ying (1997) analyzed 20-year heights and Xu et al. (2000) analyzed 20-year volume and weevil attack in relation to ecological characteristics at the sites of planting and origin.

Table 1 shows weevil attack levels at several of the eight IUFRO sites (ranging from 49°48' N to 55°04' N), that sustained the heaviest attack. Also shown

is a weevil-free site at Rennell Sound, QCI, which was used to quantify potential height loss caused by weevil attack. Although not part of the IUFRO trials, a provenance trial at Sayward (Bigtree Creek, EP 702.03) on Vancouver Island is also included in Table 1. Surplus material from the IUFRO collections, including additional provenances and OP families, was planted at this site (Alfaro and Ying 1990; Ying 1991). Even though this site had design shortcomings (such as no replication of plots), the weevil attack results have been very informative. The results in Table 1 are based on data gathered from these provenance trials after 20 years, which follow up to 12 years of heavy and repeated weevil attack.

TABLE 1 *Geographic locations, years of observation, and weevil attack levels in the Sitka spruce provenance trials*

Trial	Latitude (°N)	Longitude (°W)	Elevation (m)	Years of attack data	Cumulative attack (%)	Mean annual attack (%)
Nass[a]	55°04′	129°26′	15	12	93	37
Kitimat[a]	54°12′	128°33′	100	12	99	48
Rennell Sound[a]	53°23′	132°28′	50	0	0	0
Head Bay[a]	49°48′	126°28′	15	10	91	33
Sayward Bigtree Creek	50°13′	125°45′	75	9	95	40

a IUFRO trials (Ying 1997).

Mean annual attack (MAA) refers to the percentage of trees attacked annually by weevil, and is used as an index of both weevil attack levels and susceptibility to attack. MAA represents a successful leader kill, scored as 1 or 0 over several years during the peak years of attack, which in the case of the IUFRO trials, continued up to 12 years. An MAA value of 0% is the minimum; often 50% or more is the maximum since an attacked tree typically needs an extra year for a dominant lateral shoot to take over as the leader. Heavy and repeated attacks of 50% or more usually do not allow the trees to recover, and usually result in a permanent bushy form, overtopping, and ultimately death. MAA ranged from 0% at Rennell Sound, QCI to 48% on the mainland at Kitimat (Table 1). MAA for the entire trial is reported in Table 1 and by provenance or other entry (e.g., OP family or clone) in subsequent tables.

2.1.2 Summary of provenance program results The provenance trials show strong population source effects for resistance to weevil attack (Table 2). The worst overall provenances were the QCI sources, followed closely by coastal sources (from Oregon to north coastal British Columbia), with mean annual attack rates around 50%. Populations from the Sitka–white spruce hybridization zone and from the high-hazard dry ecological zones of southwestern British Columbia had weevil attack rates that were about half those of typical coastal wet-zone sources (Table 2, Figure 3).

Strong provenance effects were also apparent for height growth. The significant north–south latitudinal effect on height reported by Ying (1997) was evident at the QCI Rennell Sound site (Table 2, Figure 4), which suffered no weevil attack. Southern sources from Oregon (moved north 7° latitude)

TABLE 2 *Twenty-year mean heights and mean annual attack (MAA) of Sitka spruce from eight regions at five provenance trials*

		Provenance trial site									
		Nass		Kitimat		Head Bay		Sayward		Rennell Sound QCI	
Region[a]	Latitude (°N)	Mean height (m)	MAA (%)	Mean height (m)	MAA (%)	Mean height (m)	MAA (%)	Mean height (m)	MAA (%)	Mean height (m)	MAA (%)
Oregon Coast	45°	5.8	42	6.0	56	7.9	45	—	—	14.8	0
Washington Coast	47°	5.8	46	6.3	56	7.3	39	—	—	14.5	0
Southwest B.C.[b]	49°	7.7	21	7.5	28	8.7	14	4.8	32	13.5	0
Vancouver Island Coast	50°	5.3	44	5.6	53	5.8	36	4.0	44	13.3	0
Queen Charlotte Islands	53°	5.5	52	5.2	60	5.8	49	3.5	48	12.0	0
Hybrid zone (Nass and Skeena valleys)	54°	7.6	16	6.4	34	5.8	15	3.6	32	11.4	0
North Coast B.C.	54°	5.3	41	4.8	51	5.4	33	3.1	39	12.3	0
Alaska	57°	4.1	35	4.6	50	4.7	32	3.1	43	9.3	0
Site average		5.9	37	5.7	48	6.3	33	3.7	40	12.6	0

a Details of the IUFRO trials are presented by Ying (1991, 1997) and in Appendix 1A. Each region contains one to three provenance source collections.

b Provenance sources from southwest British Columbia are primarily Big Qualicum, but include Haney at the Sayward test site.

were nearly 25% taller than local sources at age 20 and exhibited nearly 100% higher stem volume. This provenance transfer effect does not show this linear trend on sites in the more continental North Coast transition zone due to climatic factors and to weevil attack levels, since weevils prefer larger, more succulent leaders (Maclauchlan and Borden 1994). The hybrid zone sources grew more slowly on more typical coastal Sitka spruce habitat (e.g., Head Bay, Sayward), but compared favourably to other provenances on sites near the northern boundary of pure Sitka spruce populations (e.g., Nass) (Table 2; Ying 1997).

Resistant populations of pure Sitka spruce had similar growth rates as susceptible sources from the same latitudes. For example, for the two populations from Vancouver Island, trees at the dry 49° site (Big Qualicum) were 13.5 m tall on average, whereas those on the west coast 50° site were 13.3 m tall (Table 2). Although weevils prefer more vigorous leaders, genetic resistance does not appear to incur a cost of reduced growth. The genetic correlation between weevil resistance and growth rate is positive in white spruce populations ($r \approx 0.6$; Kiss and Yanchuk 1991; King et al. 1997).

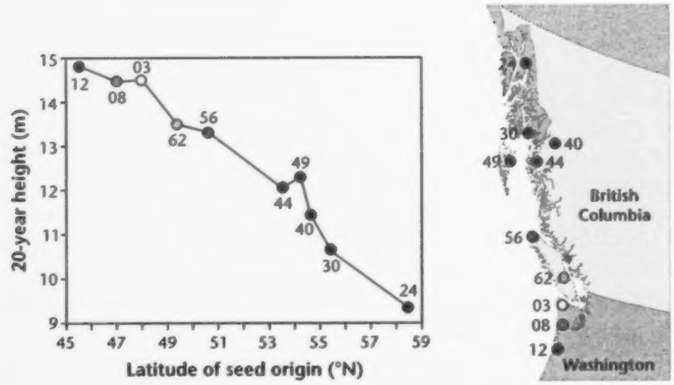

FIGURE 4 *Linear trend of 20-year height growth and latitude of seed origin at Rennell Sound provenance test site (Ying 1997). This site on the Queen Charlotte Islands shows height growth trends, free of weevil effects, for each numbered provenance.*

2.2 Weevil Resistance Screening Programs

2.2.1 Selection The selections for the testing phase concentrated on the two pure Sitka spruce provenances that did so well in the IUFRO provenance trials: the Big Qualicum (East Vancouver Island) and Haney (Fraser Valley) populations. Trees from similar environments within this high weevil hazard area were also selected based on the assumption that natural selection for higher resistance levels would increase the proportion of resistant individuals (King 1994). On eastern Vancouver Island and the Lower Mainland, where these resistant populations originate, the distribution of Sitka spruce is non-contiguous and concentrated in riparian areas and valley bottoms. Unfortunately, this is also the most urbanized part of British Columbia, which has further fragmented Sitka spruce populations. Material was also selected from similar areas in Washington, Oregon, and California. Some collections were provided by the Washington Department of Natural Resources[5] and the Oregon Department of Forestry.[6]

Material selected for screening trials included OP seed for family trials, scions for grafting, and juvenile cuttings produced for clonal trials. Selected trees were marked, referenced by GPS co-ordinates, and assigned a registration number under the BCFS Parent Tree Registration system (Appendix 2). Grafts were later gathered from trees from which OP collections had been made.

2.2.2 Screening with weevil enhancement Earlier provenance trials were initially screened by measuring attack rates in areas with natural weevil infestations (Ying 1991; Alfaro et al. 1996). However, weevil populations are typically patchy within plantations, making screening slow and potentially inaccurate. Some susceptible trees may appear resistant if they happen to be in areas of the plantation with low attack density; conversely, weevils at

5 J. deBell and K. Ripley, Wash. Dep. Nat. Resourc., pers. comm.
6 M. Bordelon and S. Lippet, Oreg. Dep. For., pers. comm.

very high population densities may overcome and attack potentially useful spruce genotypes that have moderate resistance levels. These problems were overcome by augmenting the local weevil population with adult weevils collected from nearby natural populations. Weevils were collected by clipping leaders of infested trees and then capturing the adults as they emerged from the clipped leaders. Two or three adult weevils were then placed on each tree in the fall (Figure 5) (Alfaro et al. 2001, 2008; King and Alfaro 2001). Artificial infestation immediately imposed high and evenly distributed weevil population pressure, which greatly expedited the screening process.

FIGURE 5 *Weevil augmentation (Coombs site): two or three weevils are placed in live crown in late summer or fall.*

In Sitka spruce trials, augmentation is carried out 2–4 years from plantation establishment (at tree heights of 1–2 m). Assessments can be made starting 1 year after infestation. All screening of trials was done annually by René I. Alfaro and his team at the Canadian Forest Service–Pacific Forestry Centre (CFS), Victoria, B.C. Weevil attacks for each tree were assessed based on observations of weevil oviposition points and/or emergent holes. An attack was considered to be successful where the leader was killed by larvae; failed attacks were those in which an attack was observed but the leader was not killed. Assessments were made over 3–10 years, and annual average attack was calculated. In this report, unless otherwise noted, MAA, reported as percent of trees attacked, refers to successful attack or leader kill and not just observed egg laying. MAA was recorded over peak years (from 3 to 7 years). This screening and measurement methodology is detailed by Alfaro et al. (2008), who found a high correlation between measures of egg deposition and successful leader kill.

Screening was completed on all the first-generation lines (clones and OP families), and comprised over 400 entries (Appendix 2) across 20 test sites (Appendix 1), although not all of these sites were augmented.

3 RESULTS OF SCREENING

Table 3 provides details on the trial sites, years of augmentation and assessment, cumulative attack, maximum attack level (usually the year after augmentation), and mean annual attack rate measured over years of peak impact. There was great variability in attack rates across sites. In most cases, attack rates peaked 1 year after the augmentation and then dropped off.

TABLE 3 *Geographic locations, year of augmentation, numbers of years of observation, and weevil attack levels in the clonal series (EP 702.06) and open-pollinated (OP) series (EP 702.08) trials*

Trial	Latitude (°N)	Longitude (°W)	Elevation (m)	Year augmented (no. of years assessed)	Cumulative attack rate (%)	Maximum annual attack (%) (peak year)	Mean annual attack (%) (no. of peak attack years)
Clonal trials							
Fair Harbour[a]	50°04'	127°05'	20	none (7)	74	57 (1989)	34 (6)
Espinosa Creek	50°01'	126°57'	55	none (5)	43	11 (1995)	6 (4)
Glenroy Rd.	50°20'	125°55'	25	1996 (9)	30	18 (1997)	8 (4)
Armishaw Road	50°19'	125°55'	10	1996 (3)	54	12 (1997)	8 (2)
Sandcut Creek	48°24'	123°59'	60	none (3)	8	na	na
Menzies Bay	50°07'	125°23'	60	none (3)	57	32 (2004)	23 (ongoing)
OP progeny trials							
Cowichan Lake	48°50'	124°06'	175	1996 (9)	55	30 (1996)	13 (3)
Jordan River	48°25'	124°01'	75	1994 (12)	80	40 (1995)	21 (7)
Port Renfrew	48°36'	124°23'	100	1997 (8)	69	54 (1998)	23 (4)
Snowden	50°04'	125°21'	85	1999 (9)	71	31 (2000)	24 (6)
Camp 4	50°05'	125°22'	55	1999 (7)	93	52 (2000)	42 (ongoing)
Coombs	49°18'	124°25'	100	2002 (5)	70	35 (2004)	20 (4)
Harrison	49°14'	122°01'	170	2002 (5)	86	40 (2004)	30 (ongoing)

a See Ying and Ebata (1994).

3.1 Clonal Trials

The clonal trials (EP 702.06) were established mainly by C. Ying (BCFS) to confirm the resistance observed in the provenance trials, particularly the Big Qualicum and Haney populations (Figure 3). The trials were established with either grafts or juvenile cuttings, both of which have high success rates for Sitka spruce.

3.1.1 Fair Harbour grafted clonal program Results from the original provenance trials led to Ying's discovery that trees from specific sources were free from weevil attack at the severely attacked Sayward trial (EP 702.03). To confirm that these trees did not just accidentally escape attack and that this observed resistance was repeatable and stable, a clonal trial was established in 1984 near Fair Harbour on Vancouver Island (EP 702.06-FH) (Ying 1991). The genetic resistance of individuals was tested using clones as

grafts, eliminating the random variation among seedling genotypes due to sexual recombination. In total, 640 grafts were established as four ramets in each of four replicated blocks at this test site. Scions were collected from 36 susceptible and resistant trees from eight provenances at the Sayward trial plus two trees from the Green Timbers plantation in Surrey. Resistant trees originated from the hybrid populations and from eight trees in two families from the original Haney source. The trees from Green Timbers, although of QCI origin and therefore known to be susceptible, were two of the five out of 30 000 that had survived a severe weevil attack at the Green Timbers plantation in the 1930s (Alfaro and Wegwitz 1994).

Weevil populations were not augmented at Fair Harbour, and weevil attack was initially very low (0.5%) in 1986. MAA increased rapidly to 22% in 1988, reached 57.3% in 1989, and levelled off to 22.1% in 1990. This trial (Ying 1991; King 1994; Ying and Ebata 1994) strongly supported the results of the IUFRO and Sayward trials. Figure 6 summarizes 6 years of attack data (King 1994). Mean annual attack rate among the susceptible source clones was 47.5%, similar to the rates of the susceptible sources in the IUFRO trials. The hybrids (17% mean annual attack rate) showed similar attack levels as those in the provenance trials (Table 2). Even with high weevil population pressure, mean annual attack rate of the eight clones from Haney was only 6%, and one clone showed no attacks on any of the 16 ramets. A detailed investigation of the original Sayward Bigtree Creek provenance trial (EP 702.03) showed that this particular individual, number 898 (originally from one particular Haney family: "UK–unknown"), and several other individuals exhibited total resistance or an apparent immune response to this very heavily attacked plantation. Because this total resistance has held up across many test sites, clone 898 has been particularly well-studied. This and other aspects of resistance

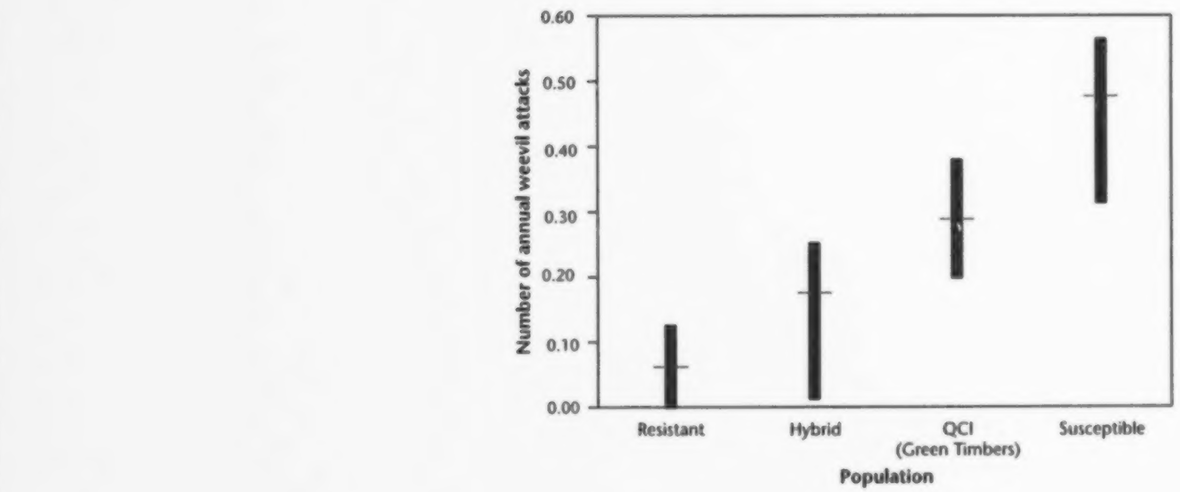

FIGURE 6 *Fair Harbour results: differences between resistant, hybrid, and susceptible clones. Wide vertical lines indicate the range of attack levels; narrow horizontal lines show overall means. QCI refers to the Green Timber individuals referenced in text.*

have been widely studied at the Fair Harbour site by CFS and Simon Fraser University entomologists (summarized in Section 4).

Attack rates in the resistant hybrid and Haney populations were so low relative to the susceptible source clones that the distributions were non-overlapping. Even susceptible clones with the fewest attacks had very high attack rates (Figure 6). Although the grafts from Green Timbers were expected to have high resistance levels, the mean attack rate of 29% was still much lower than any of the susceptible source clones, and was lower than any expected QCI source material. This indicates that even in the highly susceptible QCI population (where *Pissodes strobi* is absent), there is a low frequency of resistance. Since there are no weevils on QCI, when that provenance is exposed to attack, it resembles an exotic pest introduction where the local population has had no opportunity to evolve resistance, which results in very high attack rates and negligible resistance.

3.1.2 Sayward and other clonal trials (EP 702.06) Three clonal trials were established in 1991 and 1992 using juvenile cuttings or grafts. One site was installed in 1991 near Zeballos (Espinosa Creek, EP 702.06.2-EC), and two sites were planted at Sayward in 1992 (Glenroy Road, EP 702.06.3-GR and Armishaw Road, EP 702.06.4-AR; Appendix 1B). These trials included a more intensively sampled selection of trees from within the following provenance sources: (1) Haney (University of British Columbia Malcolm Knapp Research Forest and adjacent sites in Maple Ridge, especially Kanaka Creek), (2) Big Qualicum River on eastern Vancouver Island, and (3) selections from these two sources from the Nass and Kitimat IUFRO and Bigtree Creek trial sites. Also included were trees from natural populations around the Squamish area on the mainland south coast. Some known susceptible individuals, mainly from the IUFRO trials, were also added. The design was similar to Fair Harbour's, with four replicates of four-tree-row plots. The Glenroy and Armishaw Road sites were augmented with weevils in September 1996 in half of the replicates. Espinosa Creek was left untreated to allow a natural weevil population to build up for comparison purposes.

Other clonal trials were established in 1997 at Menzies Bay and Sandcut Creek near Jordan River (southwest Vancouver Island). The test material for these trials was surplus grafts and juvenile cuttings from other clonal trials. The plot design was incomplete due to material availability. These two trials were not augmented, but natural weevil attacks were substantial at the Menzies Bay site and have been included in this analysis. Sandcut Creek, with only 8% cumulative attack by the last assessment, was excluded from the analysis.

More detailed results are presented below (Section 3.2) for the OP trials, which included more extensive sampling. Random samples were taken within the resistant and susceptible regions rather than re-testing selected trees from the provenance trials that had been emphasized in the clonal trials. Comparisons of resistant (Big Qualicum) and susceptible regions (western Vancouver Island and QCI) for the clonal (EP 702.06), OP (EP 702.08), and IUFRO trials are presented in Figure 7. Resistant populations sustained approximately half the attack levels of susceptible populations over a wide variety of sites and test material. The overall mean annual attack rate for the combined OP trials analysis (ALL: Figure 7) was 23% for resistant material and 45% for susceptible sources.

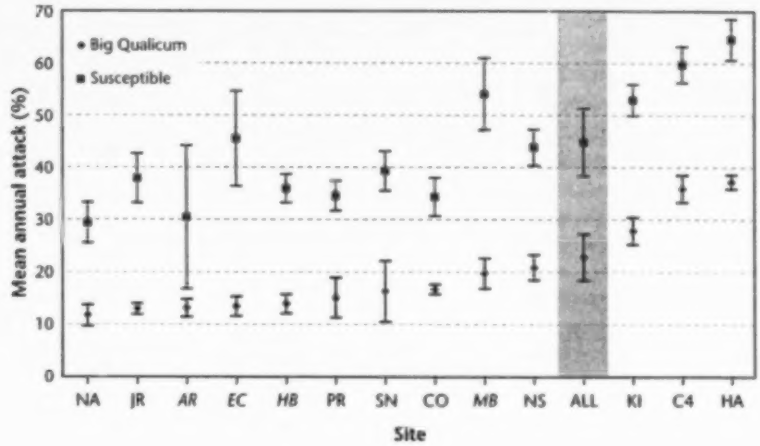

FIGURE 7 *Mean annual attack rate of the East Vancouver Island resistant source (Big Qualicum) compared to typical susceptible sources across sites reported by increasing hazard scale. NA: North Arm; JR: Jordan River; AR: Armishaw Road; EC: Espinosa Creek; HB: Head Bay; PR: Port Renfrew; SN: Snowden; CO: Coombs; MB: Menzies Bay; NS: Nass; ALL: overall mean of all open-pollinated families adjusted across all sites; KI: Kitimat; C4: Camp 4; HA: Harrison. Italics indicate clonal trials.*

3.2 Weevil Screening Family Trials (EP 702.08)

The family trials were established by John N. King as part of the Sitka spruce weevil resistance breeding program and were used to screen and select a resistant population for the provincial Sitka spruce resistance improvement program (King and Alfaro 2004). Originally, these trees were selected throughout the high-hazard zone (Ying 1991; King 1994). After the results of the Jordan River series (EP 702.08-JR) refuted the hypothesis that the resistance was broadly based in the high-hazard zone (King et al. 2004), additional collections were made to better delineate the boundaries of the resistant populations (Appendix 1C: EP 702.08).

3.2.1 Jordan River series (EP 702.08-JR) The Jordan River series was the first of the family trials to be established and the first screening trial to be augmented with weevils. This first systematic collection in the defined resistant high-hazard zone was designed to sample populations along a north–south transect down eastern Vancouver Island and western Puget Sound (from 50°02′ N to 46°32′ N). This series has been intensively studied, particularly to evaluate host resistance and population dynamics of insect infestations (King and Alfaro 2001; King et al. 2004; Alfaro et al. 2008).

This series included 67 OP families and six bulk seedlots. Seven OP families from the Queen Charlotte Islands, and bulk seedlots from four different low-hazard wet areas of western Vancouver Island, as well as one each from coastal Washington and Oregon, were used as susceptible controls based on the IUFRO trial data. In 1992, one trial site near Jordan River (702.08-JR) and one near the north arm of Cowichan Lake (referred to as North Arm) (702.08-NA; Appendix 1C) were established with 24 replicates of single-tree

plots. These trials were augmented with adult weevils in fall 1994 at Jordan River (10 replicates) and spring 1996 at North Arm (15 replicates).

In the infested replicates, attack levels were highest in the first year of infestation (40% at Jordan River in 1995 and 30% at North Arm in 1996), and decreased in following years. By 2003, the attack rate at Jordan River was 10%. At its last measurement in 2000, the attack rate at Cowichan Lake was 6%. Cumulative attack levels were 80% at Jordan River and 55% at North Arm (Cowichan Lake) by 2006 and 2005, respectively (Table 3).

The buildup of the weevil population and its subsequent decline is similar to that which occurred at the Fair Harbour clonal trial (Ying 1991) and is a common pattern (Figure 8). The detailed observations made, particularly at the Jordan River site, provide abundant data to study the population dynamics of an insect outbreak (Alfaro and King, unpublished data). Alfaro et al.

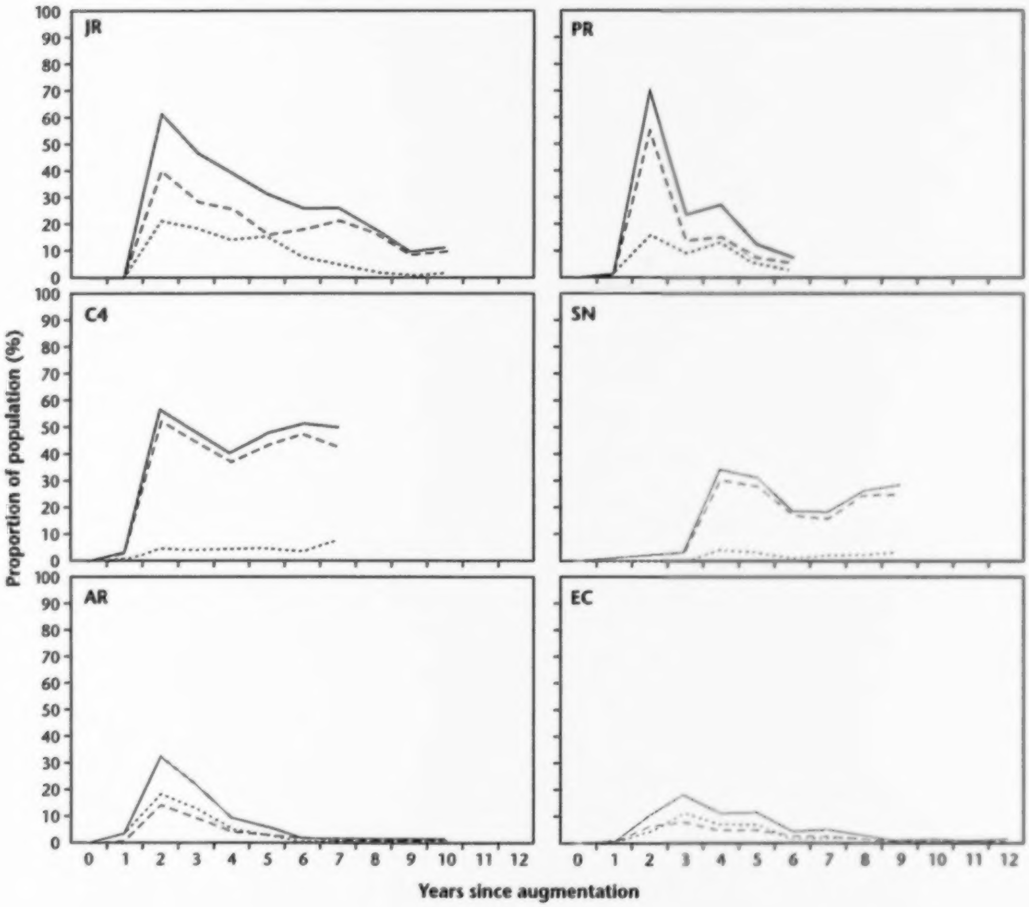

FIGURE 8 *Weevil population dynamics at six of the screening sites since weevil release. Solid lines indicate total (failed and successful) attack rates, dashed lines are leader kill rates, and dotted lines are failed attacks that did not result in leader kills. JR: Jordan River; PR: Port Renfrew; C4: Camp 4; SN: Snowden; AR: Armishaw Road; EC: Espinosa Creek (see Appendix 1 for details).*

(2008) investigated the cumulative attack over time and found that resistant genotypes could be consistently identified with as few as 10 replicates per family after 50% cumulative attack, further highlighting the effectiveness of weevil augmentation for rapid resistance screening.

Based on a mixed-effects model, the predicted results, including mean annual attack rate (1994–2000) and successful egg deposition rates, are summarized by provenance source populations in Table 4 (King et al. 2004). Weevil damage supported the IUFRO trial results—indicating that genetic resistance is strongly associated with the dry high-hazard region and that annual attack rates for individuals from these dry source areas were half the average rate of attack on individuals from most of the other sources, and one-third the rate of QCI sources (King et al. 2004). The analysis of height before weevil augmentation indicated the same latitudinal gradient in growth rate observed in the provenance trials, where southern provenances grew faster (1.2 m for Oregon and Washington sources vs 1.08 m for the East Vancouver Island sources at the North Arm site and 1.8 m for Oregon and Washington sources vs 1.6 m for East Vancouver Island sources at Jordan River).

TABLE 4 *Provenance source levels for mean annual attack (MAA) and evidence of eggs at two sites in the Jordan River series trial (EP 702.08-JR)*

		Jordan River			North Arm		Overall
Provenance	**Code**	**MAA[a](%)**	**Rank**	**Eggs[b](%)**	**MAA(%)**	**Rank**	**MAA(%)**
Fanny Bay	5	12	1	79	8	2	10
Comox	4	13	2	69	10	3	11
Nanoose	7	17	4	96	7	1	12
Qualicum	6	13	3	79	13	6	13
Texada Island	3	20	5	97	11	4	15
Campbell River	1	21	6	92	11	5	16
Oyster Bay	2	29	8	96	13	7	21
Hamma Hamma, Wash.	11	28	7	88	16	8	23
Forks, Wash.	22	34	11	100	17	9	26
Dougan Lake	8	34	10	94	19	10	26
Hood Canal, Wash.	10	33	9	97	20	12	27
Pe Ell, Wash.	12	34	13	100	20	11	28
West Vancouver Island	21	36	14	100	21	13	29
Sequim, Wash.	9	34	12	93	24	14	29
QCI	31	40	15	99	29	15	35
Necancium, Oreg.	23	40	16	100	30	16	35
Overall mean		27			17		

a Mean annual attack rate in all replicates.
b Cumulative percent of trees with evidence of eggs in the infested replicate.

Resistance is not as widely based within the dry zone as was originally postulated (King 1994). On eastern Vancouver Island it is quite concentrated close to the original Big Qualicum source collection (King et al. 2004). Sources collected from Comox to Nanoose Bay on eastern Vancouver Island, closest to the original IUFRO source, exhibited the strongest resistance effect (Table 4: source codes 4–7), and appear at the centre of the strong genetic resistance identified as the Big Qualicum and East Vancouver Island resistant sources. They were significantly more resistant than the other populations

in this high-hazard zone. Most southern source families in this high-hazard zone (especially those in Washington) did not prove significantly more resistant than QCI sources, although some populations directly north of these Big Qualicum sources (Table 4: source codes 1–3) did show an intermediate level of resistance, but were still significantly more susceptible than Big Qualicum parents (King et al. 2004).

3.2.2 Port Renfrew, Camp 4 series OP trials (EP 702.08-PR, 702.08-C4)

The Port Renfrew series was collected in 1991 and 1992 from a variety of sources, mainly from areas in the drier biogeoclimatic variants. Collection areas included the Sunshine Coast, Vancouver Island, and Whidbey Island and eastern Puget Sound in Washington. Some California collections were also included. Originally, California trees were collected because there is no historical evidence of weevil attack in California; however, that area is outside the range of *Pissodes strobi* (Langor and Sperling 1995), and none of the California trees could survive our winters. Five screening sites were established: Port Renfrew, Snowden seed orchard near Campbell River, Deena on the Queen Charlotte Islands, and two sites in the United States.

Results from the Port Renfrew series provide good support for those of the Jordan River series (King et al. 2004) where, at least on Vancouver Island, the resistance was not broadly based in the high-hazard zone but rather appeared to be concentrated very near the original Big Qualicum source. Families from Hilliers, near Coombs in the middle of this zone, and from Miracle Beach were by far the most resistant. As in the Jordan River series, families from ecologically similar sites in Washington (Puget Sound, Whidbey Island, Tulalip, and Seattle) performed poorly. Provenance sources from East Vancouver Island but north of Campbell River (Amor de Cosmos and Salmon River near Sayward) also showed poor resistance performance. Sunshine Coast–origin trees performed well but not as well as the highly resistant East Vancouver Island sources. Sunshine Coast–origin trees had mean annual attack rates similar to those of nearby populations, such as Texada Island (tested in the Jordan River series) (Table 4).

Additional trials were included to complement the Port Renfrew trial. They were located at Camp 4 in the Snowden Demonstration Forest, Campbell River. The families for the Camp 4 series trials were gathered in 1995, mostly using helicopter collections made in the Fraser Valley in 1994 (63 OP families). They were used to capitalize on the resistance associated with the IUFRO Haney provenance, assuming there was a broad resistance distribution in the area. Another 27 parent trees from the Washington Cascades and the Oregon coast were included. It was hypothesized that the steep ecological cline from the coast to the interior could have resulted in the Cascade spruce populations developing some weevil resistance as a result of natural selection in these high-hazard environments. Five previously tested Queen Charlotte Islands OP families plus four previously tested western Vancouver Island seedlots were obtained from the BCFS Tree Seed Centre and were included as susceptible controls. Progeny were planted near Campbell River (Camp 4), Sayward (Derby), and Port Alice (Victoria Lake) (Appendix A1). The trials used the same design as previous test series. Excess stock was deployed in a weevil-free trial near Sandspit (Spectacular Gorge, QCI). The Camp 4 site was augmented with weevils in the fall of 1999 and soon reached the highest infestation rates ever observed in progeny trials. Unlike other sites, such as Jordan

River (Table 3), cumulative attack at the Camp 4 site had reached 93% by 2005 after only 4 years, with no observed collapse of the weevil population.

In this heavily infested site, the best ranked families were from the Fraser Valley, except for the Coombs and Big Qualicum bulk collections used in most trials as a comparison standard. The distribution of the parents of these families ranged from 122°16′ w (Hatzic Slough) to 123°06′ w (Tsawwassen). The original Haney parents of the IUFRO series originated from 122°36′ (University of British Columbia Malcolm Knapp Research Forest). As in the other OP series, the U.S. parents showed very little resistance, although a few trees from higher elevations in the Cascades (Issaquah and White River) were in the top quartile.

3.2.3 Coombs series (EP 702.08-CO) The Coombs series was designed to test the two resistant populations from the IUFRO trials (Big Qualicum and Haney) against each other and in complementary environments to provide information on their relative resistance. Trees from 128 selected families were planted at three sites: Coombs on Vancouver Island, Harrison Mills in the Fraser Valley, and Waterfall Creek in the Queen Charlotte Islands (Appendix 1A). The Coombs and Harrison sites were also chosen because they were easy to access, which facilitated their further use in detailed investigations of putative resistance mechanisms. Selection efforts concentrated on collecting open-pollinated seed in areas around Haney (22 parent trees) and Qualicum (55 parent trees). Eleven susceptible genotypes, six from the Queen Charlotte Islands and five from western Vancouver Island, were deployed as standard susceptible controls. Four Qualicum and three Haney families previously identified as resistant were included as standards. U.S. agencies also provided material: the Oregon Department of Forestry supplied 20 parent tree selections from the Jewel area west of Portland, and the Washington Department of Natural Resources procured 13 selections from western Washington State.

As with the Camp 4 site, the Harrison site was heavily attacked. It had 86% cumulative attack after only 3 years of infestation (Table 3). Similar to the Armishaw Road clonal site (Section 3.1.2), there were no significant differences overall between the Haney and Big Qualicum sources, even in the severely attacked Harrison site. Good families were from sources that included Coombs and Qualicum, as well as Aldergrove and Burnaby Lake in the Fraser Valley. U.S. families were ranked 70th and below. Except for the few trees mentioned in the Camp 4 analysis (Section 3.2.2), no regional effect for resistance has been found in any U.S. population.

3.3 Summary of Screening: Distribution of Resistance

The provenance trials (Table 2; Ying 1997) indicated geographic regions of resistance: the hybrid area of northwest British Columbia and two provenance sources within the high-hazard region of southwest British Columbia (Haney and Big Qualicum). King et al. (2004) found that the resistance from the high-hazard region in southwest British Columbia, particularly on East Vancouver Island, is not as widely based (Table 4) as had been originally hypothesized (King 1994). Screening results extended resistant source regions beyond those identified in the provenance analysis (Table 2) to include areas where susceptible populations were found in the high-hazard zone and adjacent areas, particularly those just north of the originally identified Big Qualicum region (i.e., Campbell River and Texada Island; King et al. 2004).

Table 5 summarizes the OP series results. The Big Qualicum population in this table is referred to as Qualicum because it extends beyond the Big Qualicum River from Nanaimo to Miracle Beach. The provenance source originally referred to as Haney is similarly identified as Fraser Valley to more accurately describe its extent. "Adjacent" as defined by King et al. 2004 includes Campbell River and Texada Island, and extends through the Sunshine Coast and in this table is called Sunshine Coast and other high-hazard zone resistant parents.

TABLE 5 *Mean annual attack (MAA) and standard errors (SE) for different regions in the open-pollinated trials (based on King et al. 2004 analysis)*

	Jordan River[a]		Port Renfrew[a]		Camp 4		Coombs[a]		Overall	
Region	MAA (%)	SE	MAA (%)	SE	MAA (%)	SE	MAA (%)	SE	MAA (%)	SE
Hybrid zone	na	na	20[b]	5.0	54[b]	4.5	na	na	35[b]	6.9
Qualicum	12	1.5	15	1.5	35[b]	4.8	25	1.9	21	4.4
Fraser Valley	na	na	17[b]	6.8	37	1.8	27	2.3	24	4.8
Sunshine Coast and other high-hazard zone resistant sources[c]	16	2.6	19	2.5	48[b]	7.3	17b	6.8	25	5.3
High-hazard zone susceptible	27	1.9	35	2.0	47	2.3	47	3.3	39	6.2
QCI	36	3.9	38	3.9	65	2.7	55	4.5	48	2.9
Vancouver Island Coast	30	4.4	35	2.4	54	5.2	46	5.9	42	6.6
Washington Coast	27[b]	9.5	40[b]	9.1	na	na	51[b]	9.9	44[b]	8.3
Oregon Coast	37[b]	11.0	na	na	65	2.7	51	3.0	46	6.6

a Combined sites analysis as per King et al. (2004).
b Limited sample size.
c Referred to in King et al. (2004) as adjacent.
NOTE: na = not available.

Table 5 corresponds well with King et al. (2004). It shows sharply defined regions of resistance, particularly the Fraser Valley and Qualicum regions. Both these regions support Sitka spruce with high weevil resistance. In the Coombs series analysis that specifically compared these two resistant regions, no significant differences were detected ($P = .24$). Hybrid zone populations from the northwest were not tested as part of the OP trials, but where they were represented in the clonal trials, such as Armishaw Road, hybrids had similar resistance levels as populations from the resistant regions of southwestern British Columbia (results not shown), as indicated in the IUFRO trials (Table 2). Populations from the rest of the high-hazard area, mainly Washington but also southern Vancouver Island including Duncan and south to Saanich, are susceptible, but the Sunshine Coast and directly adjacent areas are more resistant than earlier studies suggested (e.g., King et al. 2004).

Figure 9 incorporates results from all four of the OP family series trials and graphically demonstrates the distribution of naturally occurring resistance found in the high-hazard zone of southwest British Columbia (Appendix 3). Three to 30 trees per provenance source were included. The strongly defined resistance boundaries of the Fraser Valley and the Qualicum regions are evident. They transition over relatively short distances to susceptible regions to the north (Salmon River, Amor de Cosmos) and south (Dougan Lake, Saan-

ich, Tulalip). Populations from the Squamish area are also highly resistant (a result indicated in the clonal trials).

Table 5, Figure 9, and Appendix 3 largely support the conclusions of King et al. (2004), based on the analyses of the Jordan River series data, but extend these results to the following:

- resistance is not broadly based throughout the high-hazard area of southwest British Columbia but is localized around the two populations identified originally in the IUFRO trials: the Qualicum area of Vancouver Island (originally Big Qualicum) and the Fraser Valley (originally identi-

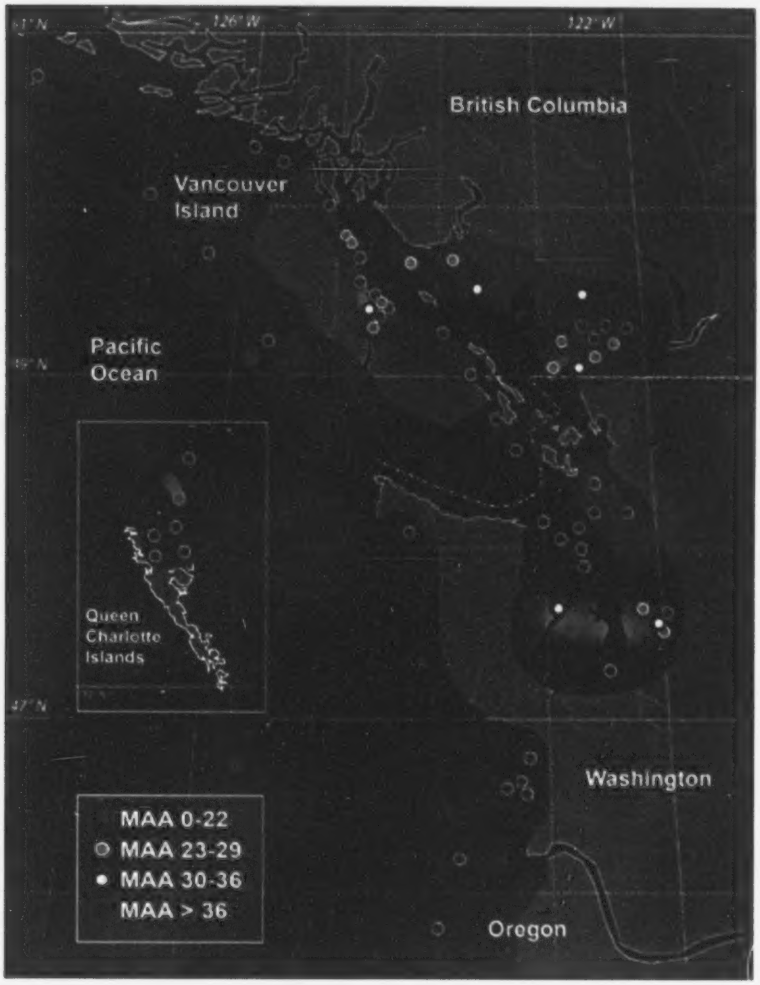

FIGURE 9 *Resistant provenances by mean annual attack (MAA) level, and zones of high and low natural resistance. MAA is expressed as a percentage. The resistant zone is shown in red, the susceptible zone in blue shades (intermediate in yellow).*

fied as the Haney area near University of British Columbia Malcolm Knapp Research Forest);

- the clonal trials identified the Squamish area as a resistant region within the high-hazard area of southwestern British Columbia, and the OP series extended the resistance into the Sunshine Coast and Texada Island;
- no other resistant regions have been identified within this high-hazard area (including none in the United States), although west of Seattle (close to the Cascades), a few populations with moderate resistance have been found;
- the clonal trials confirm the earlier provenance results indicating that the hybrid zone of northwestern British Columbia is a similar resistant region;
- on average, parent trees from these resistant regions have approximately one-half the weevil attack level of susceptible sources over a wide variety of site hazards;
- outside of these resistant regions, population sources from high-hazard areas are no more weevil resistant than other coastal sources, except the Queen Charlotte Islands and some fast-growing Oregon sources, which show even more susceptibility than expected; and
- there is significant variability in resistance between individuals within regions.

3.4 Summary of Screening: Ranking Families and Resistance Values

Although the strong provenance effect shown in both the regional analysis (Table 5) and provenance analysis (Figure 9) has been the dominant story in the resistance of Sitka spruce to the white pine weevil, there is significant variability of families within these regions (King et al. 2004). Selections from the screening programs have been used to establish seed orchards that are now delivering resistant seed using this observed variability. To differentiate these parents based on the screening analysis, we have developed a resistance value score.

A system using genetic worth is currently used in British Columbia to evaluate the potential gain of seedlots from domestic seed orchards, estimated for a given trait at harvest age. Values are derived from the breeding values of selected parents, adjusted for factors such as parental fecundity and pollen contamination (Stoehr et al. 2004). Breeding values reflect the percentage increase (or decrease) of a tree relative to the overall population mean for a trait, where a wild population of trees has a breeding value of zero. Genetic worth values are based on conventional breeding values for traits of interest, such as volume or wood density, and genetic covariances are adjusted based on pedigree data. To standardize a similar measure for weevil resistance, mean annual attack data are adjusted using a mixed effects model (King et al. 2004). The rationale for concentrating on adjusting the value for the major effect (i.e., the site hazard variability shown in Tables 3 and Figure 7) was as follows: (1) nearly all the individuals in the weevil resistance screening are first-generation selections and can therefore be considered unrelated; (2) the mean annual attack data do not fit an underlying normal distribution, which most traditional breeding value adjustments rely on (e.g., White and Hodge 1989); and (3) there is often the assumption of a multigenic model for quantitative traits, but currently, little is known about the underlying genetic models of resistance (see Section 4). After future analysis of the F_1 data provides a better understanding of the genetics of resistance, the resistance score may be adjusted to correspond more with the genetic worth system.

At this time, however, the resistance value is the mean annual attack rate, adjusted for the site hazard (Figure 7) using a mixed linear effects model (King et al. 2004). Percent mean annual attack presented in this way equates to the weevil attack susceptibility expected in a plantation established with genotypes of similar resistance value. For example, a stand established with a Big Qualicum bulk seedlot on a medium-hazard site is expected to have 23% of trees attacked in any year (Figure 7: ALL sites). Another major advantage of using mean annual attack as a basis of the resistance value score is that this number is also used as a base input to the BCFS growth and yield models for stand productivity and timber supply modelling (TIPSY and SWAT[7]). The weevil impact damage modules of the BCFS TASS stand volume simulator have scoring criteria to quantify mean annual attack rates in terms of timber volume (see Section 5).

Table 6 presents a list of top-ranked families[8] and their origins expressed as MAA with standard errors of this estimate, and resistance values. Standard errors for clones and OP families are very high, approximately one half the MAA value. Resistance values are presented as a single score in multiples of three (3, 6, 9, 12, ...) to incorporate this error implicitly. Rounding in this fashion yields a categorical or interval value that avoids false precision and allows the categorization of parents by their resistance levels. There is no "0" category for this statistical reason, but seed orchard managers can choose the best categories of parents that are available. Currently, the evaluation is based

TABLE 6 *Sample of screened families and selected clones showing mean annual attack (MAA) and standard error (SE) for series, provenances, registration number (Regno) for tested parent trees, and resistance value (see Section 3.4)*

Series	Region	Provenance	Regno	MAA[a,b] (%)	SE (%)	Resistance value
EC, MB, and others	Fraser Valley	Haney	898	n/c	n/c	3
EC and others	Fraser Valley	Haney	889	n/c	n/c	3
PR–Port Renfrew	Qualicum	Miracle Beach	1259	5.2	5.3	6
JR–Jordan River	Qualicum	Courtenay	1009	6.4	6.7	6
CO–Coombs	Qualicum	Comox	1648	6.7	3.7	6
C4–Camp 4	Fraser Valley	Bayliss	1588	8.0	4.7	9
CO–Coombs	Qualicum	Puntledge River	1709	9.8	4.9	9
PR–Port Renfrew	Qualicum	Hilliers	9057	10.4	7.2	9
JR–Jordan River	Qualicum	Deep Bay	1020	10.9	8.6	12
CO–Coombs	Fraser Valley	Aldergrove Lake	1326	11.1	5.2	12
CO–Coombs	Qualicum	Qualicum	1719	11.1	5.2	12
ALL–analysis	High-hazard zone		9016	55.0	12.0	50
ALL–analysis	West Van. Isl.		1280	55.0	12.0	50
ALL–analysis	Oregon		9042	55.0	14.0	50
ALL–analysis	QCI		90003	56.0	10.0	50

a n/c: not calculated (no attacks recorded).
b A full list of values for all tested parents is available at www.for.gov.bc.ca/hre/forgen/coastal/sitkaspruce.htm.

7 For more information or to download these models, visit the Ministry of Forests and Range Growth and Yield Modelling website: www.for.gov.bc.ca/hre/gymodels/index.htm.
8 Information on resistance value scores of all parents screened can be found at Ministry of Forests and Range: Research Branch, Coastal Tree Breeding, Sitka spruce website: www.for.gov.bc.ca/hre/forgen/coastal/sitkaspruce.htm.

on the phenotypic expression of resistance in the screening trials and does not express the underlying genetics (see Section 4).

To fit a scale comparable to genetic worth (linear increasing scale), the BCFS seed inventory system SPAR (Seed Planning and Registry Application) uses the inverted resistance value score, so that 0 is the lowest genetic worth associated with the observed maximum attack rate (50%) and 100 is the highest genetic worth and most resistant (0% mean annual attack) from the formula *GWR = 100 − (2 × %RV) where RV is the resistance value.* GWR (Genetic Worth Resistance) values for all screened parents (clones and families) are available on the SPAR website[9].

3.5 Breeding and Establishment of F_1 Trials

Based on the results from the screening trials, individuals were selected to become parents in the breeding population. Some of these have also been established in seed orchards (see Section 5). Initially, 60 parents were selected based on their phenotypic expression of resistance from weevil screening. Controlled crossing in a partial diallel design was completed, and three series of F_1 trials were established to generate a total of 300 full-sib families (Appendix 1D). Because no information on differences in putative mechanisms was available (see Section 4), resistant parents were identified by their population of origin (Big Qualicum and Haney), and diallel mating groups were constructed within these populations. Pair crosses between population groups and with susceptible parents were also made (see King and Alfaro 2004 for details). This approach was used to test the hypothesis that these populations might have different resistance characteristics. Since then, resources have been focussed on characterizing both populations and individuals for known mechanisms based on their phenotypic expression. Based on these results, there are plans to establish a second-phase breeding population to help us better understand the inheritance of these mechanisms and their roles in observed phenotypic resistance. The first of the F_1 trials at Jordan River Main (EP 702.10-JM1) underwent its first assessment in fall 2008, 1 year after weevil enhancement. This culminates a full evaluation of weevil resistance only 5 years from seed.

4 MECHANISMS OF RESISTANCE

Artificial weevil infestation is cheap, effective, and quick (Alfaro et al. 2008); however, it provides only a phenotypic measure of resistance with limited information on the mechanisms and factors influencing resistant genotypes. The knowledge gained in nearly 30 years of research into this resistance has been used as a textbook case of host resistance to stem-invading insects. Three general types of resistance are defined by Alfaro et al. (2002): (1) toxicity, (2) repellence or hindrance (and avoidance); and (3) phenology and synchronicity. Toxic effects can be antibiotic effects that harm the insect, or antixonetic effects that deter colonization by harming the insect's reproductive abilities. Both antibiotic and antixonetic effects, in turn, can be caused by straight toxic effects or by nutritional deprivation. Repellence hinders the insect's ability to attack the tree for both feeding and reproductive purposes,

9 For more information and use of the SPAR system see www.for.gov.bc.ca/HTI/spar/

and can extend to pitching out of eggs and larvae. Phenology and synchronicity may delay the insect's feeding and reproductive cycles, and in doing so, help parasitizing insects and diseases that attack the pest.

Resistance mechanisms can also be classified as constitutive or inducible defences according to their permanence in time (Alfaro et al. 2002). Constitutive defences are permanent structural or chemical defence systems that occur regardless of the presence of the attacker. Examples include trichomes, thorns, latex, resin canals, sclereid cells, and an array of defence chemicals, including resin component chemicals. Inducible defences are activated in response to attack. Examples include the mobilization of defensive chemicals to the site of wounding, and the production of traumatic resin canals in conifers in response to insect and fungal attack. Plant defences and their effects on insects are dynamic and interactive. The interaction of the host, its phenology, the insect pest, and associated parasites and predators can be quite complex (Panda and Khush 1995; Alfaro et al. 2002).

4.1 Resistance Mechanisms to Weevil Attack in Spruce Populations

4.1.1 Feeding, egg laying, failed and successful attack incidence When *Pissodes strobi* feeds on spruce, it really does no harm to the tree. It is only after fairly massive egg laying that the tree suffers. In a study of spruce populations from the British Columbia interior (primarily white spruce), leaders were successfully killed if 140 eggs or more were laid (Alfaro et al. 1996). The number of eggs laid could correspond with the success of weevil attack; values higher than approximately 140 eggs may be a threshold for leader kill.

There is a significant and strong correlation between our phenotypic assessment of leader damage and successful egg deposition. Three of the four highly resistant sources (Fanny Bay, Comox, and Qualicum) showed significantly fewer trees with egg deposition than most other sources in the Jordan River series (Table 4). Thirty-four of the 67 OP families tested had successful egg depositions on 100% of the trees. In the best four families selected from this trial, only 50% of the trees had any eggs at all, and those that did had significantly fewer eggs than trees from other families (Table 4).

Much research on feeding, egg-laying, and weevil top-kill has been conducted on the 898 clone since this highly resistant individual was first noticed at the Sayward (Bigtree Creek) trial (Alfaro and Ying 1990). This research has been well replicated in many trials, including Fair Harbour (King 1994), Espinosa Creek, and Sandcut Creek, and in trials conducted by the Pacific Forestry Centre in Victoria, Western Forest Products Ltd. Saanichton Forestry Centre, and the B.C. Forest Service Cowichan Lake Research Station. Detailed feeding and oviposition observations of uncaged weevils and weevils caged onto spruce leaders have been made (L. VanAkker and R. Alfaro, unpublished data). Caged weevils fed on clone 898 but usually lower down in the crown than typical; uncaged weevils usually moved to a different clone. Very little or no oviposition, and even fewer successful emergent holes were observed on the hundreds of ramets studied, even where weevils were caged. Reports on hindrance and toxicity of clone 898 are reported below.

4.1.2 Repellence or hindrance defences against insects Several hindrance mechanisms have been noted, the main one being resin canal formation. This includes increases in natural levels of constitutive resin canals in the bark (Tomlin and Borden 1994; Alfaro et al. 1997) and the formation of rings of traumatic resin canals induced by weevil feeding and oviposition punctures

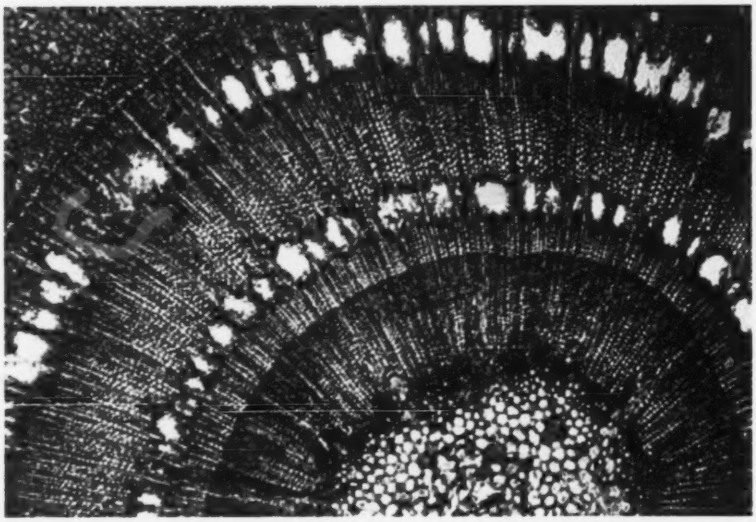

FIGURE 10 *Rings of traumatic resin canals (Alfaro 1995).*

(Alfaro 1995; Figure 10). Sclereid or stone cell hindrance has also emerged as a possible constitutive repellence type of resistance (Grau et al. 2001). Sclereids are tough cells with thick, typically lignified secondary walls. They can form a sort of armour plating against perforation by insects. One of the functions of sclereid cells in plant tissue is in deterring phytophagous insects (Carlquist 1984; Chakravarthy et al. 1985). Strong population and individual differences in these traits were observed in the screening results (Section 4.2).

4.1.3 Toxic defences: the 898 story An interesting putative resistance mechanism has been observed: a strong toxic response resulting from a potential biochemical element that aborts weevil egg development (Sahota et al. 1994, 1998). So far, this resistance has been studied only in one Sitka spruce clone: 898, which has maintained an almost total resistance to high population attack levels in well-replicated field conditions (King 1994). Other highly resistant individuals exist but have yet to be as well studied. The resistant 898 clone inhibits the expression of the vitellogenin gene in weevils after they feed. Vitellogenin is an egg-yolk protein precursor necessary for the maturation of eggs in reproductively active female weevils (Leal et al. 1997). Weevils that fed on resistant ortets or cuttings of the 898 clone had fewer eggs form in their ovaries, and ovaries of *Pissodes strobi* females that fed on this clone did not mature. Levels of ovarian growth and expression of the vitellogenin gene were also reduced in weevils that fed on severed leaders of the resistant 898 clone relative to those that fed on severed leaders of a susceptible family. Weevils that were force-fed one dose of extract from resistant leaders, followed by extract from susceptible trees, exhibited 60% inhibition of oocyte growth and 48% less expression of the vitellogenin gene relative to insects that were given only the extract from susceptible trees (Sahota et al. 2001). Nutritional defences could also account for this resistance, but further research is needed to confirm the underlying mechanism. Clone 898 has also been studied for constitutive and

induced hindrance traits. Although it does well in these rankings (Alfaro 1996; McKay-Byun et al. 2006; L. VanAkker and R. Alfaro, unpublished data), results for this individual are within the range of statistical norms.

4.1.4 Phenology, population dynamics, and biological defences The role of phenology in resistance has also been investigated (Alfaro et al. 2000, 2002). Phenology includes the synchronization of the growth and life cycles of the tree with those of the weevil and the weevil's predator and parasite populations. It has been noted that in Sitka spruce, trees that flush earlier may have less weevil damage (Hulme 1995).

This interaction may be a strong part of the population dynamics illustrated in Figure 7, which shows weevil attack dynamics on six test sites, all of which were augmented except for Espinosa Creek. The most common trend was a marked increase over the background weevil attack level immediately after augmentation, followed by a decline as the corresponding predator populations built up (R. Alfaro, unpublished data). Sometimes an abrupt collapse (e.g., Armishaw Road) was observed rather than a decline (e.g., Jordan River), and in some cases, weevil populations declined only marginally (e.g., Camp 4). Other sites that suffered repeated high attacks were Harrison and Menzies Bay (Table 3), and provenance trials at Kitimat and Sayward Bigtree Creek (Table 1). Research into the population dynamics of insect outbreaks has been a valuable adjunct to the screening work (R. Alfaro and J. King, unpublished data).

4.2 Characterizing Resistance Mechanisms of Known Resistant Populations

Specific resistance mechanisms used by resistant populations and individuals were characterized to test how accurately they can be used to predict or describe the phenotypic resistance observed in the attack data. Studies of white spruce populations indicate that traumatic resin canals are strongly associated with resistance (Alfaro 1995; Alfaro et al. 1996, 2004). However, this resistance mechanism appears to be less strongly expressed in Sitka spruce than in white spruce, and may account for the far higher weevil susceptibility in Sitka than white spruce (Humble et al. 1994). In the hybrid zone in northwestern British Columbia (the Nass and Skeena River valleys), the most significant predictive variables for traumatic resin canal levels in spruce trees were distance from salt water and degree of white spruce genotypes in the hybrid (O'Neill et al. 2002).

King et al. (in prep.) studied the resistance of cloned individuals from the resistant populations of southwest British Columbia. The objective was to determine if these populations had the same type of resistant mechanisms by specifically testing for repellency of constitutive and traumatic resin canals and sclereid cells. The authors also evaluated how these hindrance traits could best predict phenotypic resistance scores based on mean annual attack. The Fraser Valley population had nearly four times the sclereid density of susceptible populations. Although the Big Qualicum population had the same high resistance, it was expressed primarily through increased constitutive resin canals. Sclereid cell density had the highest predictive power for resistance score (Figure 11). Contrary to observations by O'Neill et al. (2002), traumatic resin canals were not significantly correlated with mean annual attack rate, and did not show significant population differences. Further research is planned for the next phase of the breeding plan, and will include using clonal embling lines.

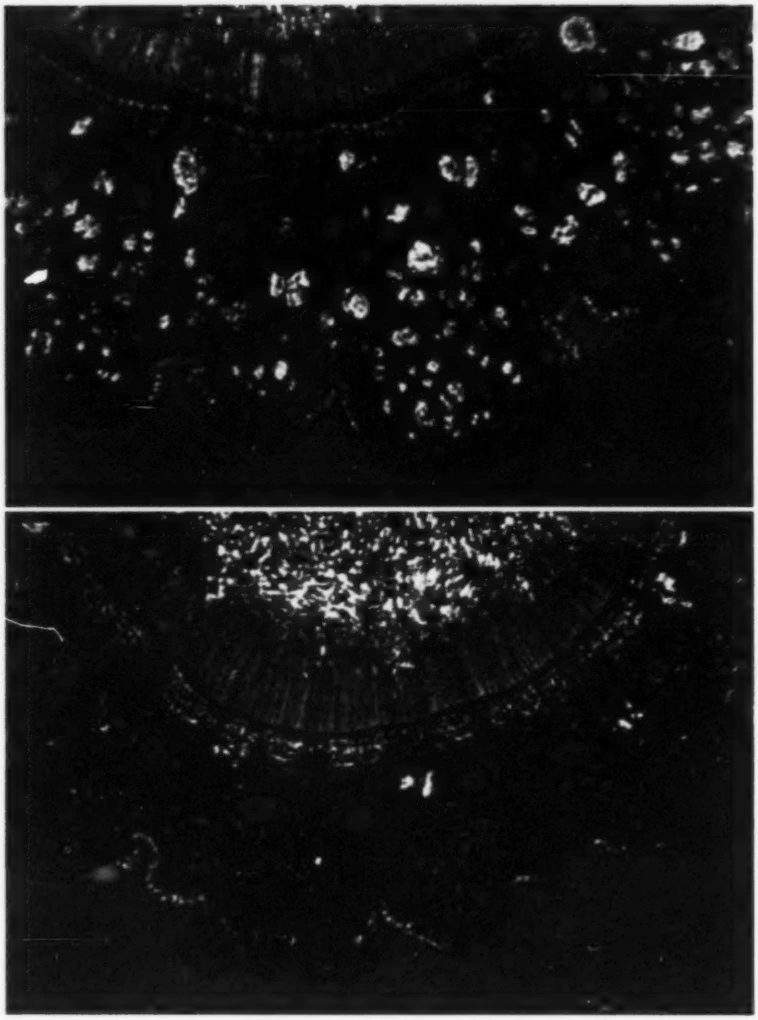

FIGURE 11 *High sclereid density (top) and low sclereid density (bottom) clones.*

4.3 Understanding the Genetic Basis of the Expressed Phenotypic Resistance

Insect resistance in plants is usually complex, continuously variable, and most likely controlled by the segregation of multigenic quantitative trait loci (Gatehouse 2002). Strongly featured in this resistance are both constitutive (Tomlin and Borden 1994) and induced (Alfaro 1995) resin defences. The genomic, molecular, and biochemical makeup of conifer terpenoid resin defence pathways is complex and multi-faceted (Huber et al. 2004), lending support to the hypothesis of complex quantitative trait loci control. Major gene or R-gene resistance is common in plant resistance to rust pathogens but has also been noted in phloem-feeding insects (Fernandes and Negreiros 2001; Harris et al. 2003). Although a hypersensitive reaction or galling is a commonly observed feature in this type of resistance, it is not always clearly indicated (Harris et al. 2006). There are some important features of major

gene resistance in Sitka spruce to the white pine weevil, particularly the discrete geographic distribution of resistance (Figure 9) but this in itself does not prove the case. Family and within-family variability is being analyzed using new phenotypic weevil data from the F_1 trials to test the hypothesis of major gene segregation. Confirmation will require the use of more extended pedigrees for segregation analysis and/or molecular genetic techniques based on linked molecular markers. The work of the spruce genome project[10] at the University of British Columbia will be instrumental in this understanding.

5 DEPLOYMENT

5.1 Delivery Program

For successful deployment of Sitka spruce, two components must be considered: the delivery program, consisting of seed orchards, vegetative cuttings, and associated works; and silvicultural guidelines for the deployment of spruce based on hazard evaluations and risk assessments.

Deployment guidelines will be updated to include seed transfer and results of the Sitka spruce improvement program for weevil resistance. Trials have shown that moving seed 5°, 6°, or even 7° north of its source, in similar climatic conditions (e.g., maritime or submaritime climatic regimes with similar numbers of frost-free days, mean annual and minimum temperatures, etc.), does not compromise survival and growth (Figure 12). The extremely restrictive transfer guidelines for the Coast-Interior transition will also be examined, but given the steep environmental clines and the adaptational clines exhibited in Sitka-hybrid spruce, transfer in this area will likely remain limited and will rely more heavily on local seed sources with desirable phenotypes (e.g., B+ seedlots).

5.1.1 Seed orchards and the B+ seedlot program The greatest effect observed so far in the Sitka spruce weevil resistance breeding program is the significant and overwhelming provenance effect for resistance (King et al. 2004; Table 5). Planting trees from resistant regions has produced seedlings that have, on average, less than half the effective attack rate of those from more susceptible sources (King et al. 2004; Figure 7, Table 5). Therefore, a low-cost deployment option, which is recommended as a priority ahead of orchard seed and is particularly valuable for low-hazard or mixture plantings on medium-hazard sites, is simply to use B+ or superior provenance seedlots, such as Big Qualicum bulk. B+ seedlots have been widely used since the early 1990s, supplanting the use of the old orchard seed that was derived mainly from susceptible regions.

Seed orchards (SOs) have traditionally been used to provide seed for commercially important species in British Columbia and species that are the focus of tree improvement programs. This policy was established based on the provincial plus-tree program. Many orchards were established in the 1970s. The Sitka spruce program included four seed orchards for coastal British Columbia: Western Vancouver Island Hovey Road SO 133, Northern Vancouver

10 For details of the UBC genomics project see: treenomix.ca/Home/ResearchAreas/FunctionalGenomicsofConiferDefense.aspx.

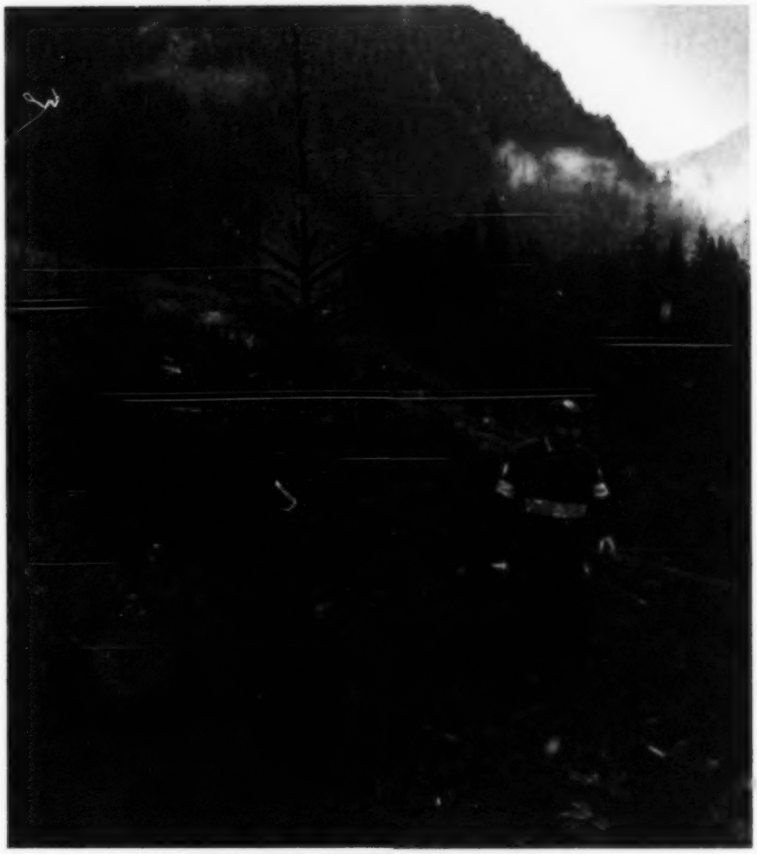

FIGURE 12 *Big Qualicum–origin spruce showing excellent growth and no weevil damage at a high-hazard site (Bish Creek near Kitimat, 53°55′ N).*

Island–Lost Lake SO 144, QCI–Moresby–Lost Lake SO 142, and Mid-Coast Yellow Point SO 147. The Western and Northern Vancouver Island orchards are no longer operational. The QCI–Moresby orchard has been re-grafted and moved to Saanichton and is being tested as part of the QCI program (Section 6.3).

The Mid-Coast–Yellow Point orchard, owned exclusively by Yellow Point Propagation, is being used primarily for seed export to the United Kingdom where there are no weevils.

The Vancouver Island and coastal mainland seed orchard programs were redirected in 1989, primarily as a result of the research documented in this report. Two orchards have been established to produce weevil-resistant seed for coastal regeneration programs: Yellow Point Propagation has established a 350-tree orchard at Yellow Point, and Western Forest Products has established a 350-tree orchard in Saanichton. Objectives of these orchard programs are co-ordinated through the Forest Genetics Council of B.C.[11]

11 See the Forest Genetics Council website www.fgcouncil.bc.ca.

5.1.2 Cuttings and somatic embling programs Bulking-up valuable material through vegetative propagation by using nursery stool beds and setting cuttings is often used in forest plantation regeneration and is widely used for Sitka spruce in the United Kingdom (Samuel et al. 2007). A fairly large program was initiated in British Columbia in the mid 1990s to produce several hundred thousand cuttings of Sitka spruce for the coastal British Columbia reforestation efforts. This initiative took advantage of the F_1 breeding program by using surplus seed produced. The program was terminated when the first phase of the breeding was finished and seed orchards became operational.

Clonal lines of emblings are part of the weevil resistance program for interior spruce; more than 1000 such lines were created and established in various field trials. A small program involving 100 Sitka spruce lines was established, none of which were kept in cold storage. It is expected, however, that a directed research effort using emblings with a range of phenotypic resistance mechanisms will be established (J. King, unpublished data). Plans for the second-phase F_1 breeding program include creating small diallel breeding units using clonal lines. This will provide important statistical replication of genotypes and will aid our understanding of the nature and inheritance of resistance mechanisms.

5.2 Demonstration and Silvicultural Trials

5.2.1 Silvicultural trials Various demonstration trials have been set up to highlight genetic resistance (Appendix 1F). Probably the most marked of these are the block plots of susceptible and highly resistant grafts at the Hisnit site, which were established by the Canadian Forest Service Pacific Forestry Centre (Appendix 1F: EP 702.11-HS). Little or no attack was noted on highly resistant grafts (including clone 898), but massive, ongoing, and repeated attack levels of 50% or more occurred in the susceptible blocks. The resistant blocks are free-growing trees, but the susceptible blocks were reduced to shrubs.

Silvicultural control techniques such as shading, clipping, insecticide use, spacing, and mixture planting have largely fallen out of favour; therefore, resistant seed is now seen as the best silvicultural option. Ecological approaches to limit the impacts of the weevil on coastal spruce plantations are discussed by Alfaro et al. (1994), who proposed the use of integrated pest management systems that would favour the weevil's natural pests. Outside of genetic resistance, the best approach may be to use biological control. The investigation of weevil collapse and population dynamics (Figure 8) suggests that some of this work (Alfaro et al. 1985; Hulme 1994) may be worth revisiting. Trials using various techniques, such as spacing and mixed species plantings, have been established (Appendix 1F: EP 702.00.01), but results have not shown effective weevil control. Deploying genetically resistant material in conjunction with site hazard evaluation is seen as a more cost-effective and robust approach over the long term.

5.2.2 Hazard evaluation trials Current deployment guidelines for Sitka spruce are extremely conservative, reflecting the species' historic susceptibility to the weevil. However, the Sitka spruce tree improvement program, as detailed here, has yielded robust material that has demonstrated durable resistance to the weevil, and good growth in height and volume.

The other major influence on weevil attack, aside from genetic resistance, is the environment. Figure 7 clearly shows the impact of increasing environmental pressure on the bulk Big Qualicum seedlot. Trying to define the factors that influence this environmental pressure is an important precursor for establishing deployment guidelines. A series of hazard evaluation trials has been established (Appendix 1F: EP 702.00.02). Initial measurements will be undertaken in 2008–2009. Site-specific empirical climate data are available from establishment in 1999 through to 2008. Additional refinement of existing weevil hazard mapping based on climate station data will also be initiated in 2008–2009. This will involve using a climate modelling approach and integrating a spatial GIS database with growing-season degree-day accumulation to indicate conditions associated with varying degrees of suitability for weevil development. Thresholds for weevil development in Sitka and interior spruce have already been established and can be interpolated in the transition zone. Results from established trials and plantations that are using susceptible and resistant seedlots will be used to refine the model. This includes developing recommendations for fine-scale spatial variation, such as aspect or microsite.

6 OTHER SPRUCE PROGRAMS

6.1 Interior Spruce Program

Weevil resistance is an important component of the interior spruce breeding program, but far more emphasis is placed on growth and yield than in the Sitka spruce program. As found by O'Neill et al. (2002) and Alfaro et al. (1997), resin canal hindrance, particularly traumatic resin canal formation, is a much stronger and more effective resistance agent in white spruce than Sitka spruce. Although provenance variation is not as apparent, there is considerable genetic resistance in interior spruce populations (King et al. 1997; Alfaro et al. 2004), and an active selection program for weevil resistance is under way.[12] Prominent in these selections are eastern North American trees that display strong and durable genetic resistance to the weevil, and which have very good height growth. Some unique genotypes, such as clone PG29, have been identified as having some of the total resistance characteristics as Sitka spruce clone 898.

6.2 Nass/Skeena Transition Program

The Coast Mountains of British Columbia provide a natural barrier between coastal Sitka spruce and interior spruce (including white and Engelmann spruce and their hybrids). However, in some areas with submaritime climates, and where rivers, such as the Nass and Skeena Rivers, open up east–west valleys through the mountain ranges, these species naturally hybridize. These hybrid zones, besides having tremendous genetic diversity due to the introgression of the two gene pools, are also areas of extreme environmental variability since they are at the transition between coastal and interior climates. In the hybrid zones, the major adaptive selection pressures on spruce seedlings include (1) weevil hazard: having a high proportion of interior spruce genes reduces weevil susceptibility by 50%, (2) frost tolerance: interior spruce has much higher frost hardiness, and (3) growth rate: having a high

12 B. Jaquish, pers. comm. see: www.for.gov.bc.ca/hre/forgen/interior/spruce.htm.

proportion of Sitka spruce genes leads to significantly faster growth. All three of these selection pressures strongly influence the health and adaptability of spruce trees but in differing directions depending on the genetic makeup of the hybrid. Frost and weevil tolerance are superior in interior spruce, while growth rate—which influences adaptability in a seedling's ability to overcome brush hazard, browsing, and weevil attack recovery—is higher in Sitka spruce genotypes. The trade-offs between Sitka and interior spruce traits in hybrid trees make it difficult to prescribe seedlots for the transition area. Seed transfer in this zone is very limited—only ± 0.5° of latitude compared to 3° for most other species. This restriction has been a challenge for resource managers trying to use spruce in this area.

In 2000, a series of trials was established using single-tree collections made throughout the hybrid area of northwest British Columbia and other spruce transition areas, and including some known F_1 and other pedigreed crosses. These trials will be assessed for growth, survival, and weevil attack in 2008–2009. Information from this assessment will be used to establish guidelines for Sitka and hybrid spruce seed transfer. It will also enhance our understanding of the importance of the genetic origin of seedlots and the effects of environmental pressures on growth, stress tolerance, and weevil attack levels. Collaborative nursery and molecular genetics projects with the University of British Columbia Centre for Forest Conservation Genetics[13] have provided important information that will support the field trial assessments and improve our understanding of the complex genetic and environmental diversity of spruce in this region.

6.3 Queen Charlotte Islands Program

The main region where Sitka spruce has remained commercially important in British Columbia is the Queen Charlotte Islands, where the terminal weevil is not present. Annual planting of Sitka spruce in the Haida Gwaii Forest District from 1996 to 2000 averaged 800 000 seedlings, with a high of 1.1 million in 1998. However, current plantings throughout British Columbia now number only about 500 000.

Genetic research on Sitka spruce in the Queen Charlotte Islands has included a series of non-IUFRO and IUFRO provenance trials (Appendix 1A: EP 702.02 and EP 702.05, Rennell Sound). These trials have had excellent growth rates, with Oregon sources attaining double the volume of local sources at 20 years (Figure 4). This increased growth potential does not appear to incur any costs in terms of damage (such as forking due to frost kill) or lower wood density. In fact, the wood density profiles of these Oregon trees appear better than local sources as the extended late-season growth also produces a much higher percentage of denser latewood (J. King, unpublished data).

Many of the U.K. Forestry Commission selections and breeding program parents in northern Britain are of QCI origin. Seventy-five of these families were selected on the basis of growth rate, stem form, and, more recently, wood density, and have been established and tested alongside 90 families of the original South Moresby seed orchard (Appendix 1D; Appendix 2E). Volume gains at rotation are predicted with confidence to be 15–20% over the average (Samuels et al. 2007). The BCFS has also established trials with weevil-resistant families on the Queen Charlotte Islands (Appendix 1D). This

13 UBC Centre for Forest Conservation Genetics. See: genetics.forestry.ubc.ca/cfcg.

provides an opportunity to analyze these families for their inherent growth potential in the absence of weevils, which cannot be done on the mainland, and to evaluate how these families will perform if planted on the Queen Charlotte Islands. If the weevil migrates there, information is already available on how weevil-resistant material can be used and deployed to protect the valuable Sitka spruce resource in that area.

7 SUMMARY AND CONCLUSION

This report presents the history and results of several decades of research on the genetic resistance of Sitka spruce to the white pine weevil. The discovery of this resistance has supplanted many of the older and less effective silviculture controls, and now is seen as the key to successfully re-introducing this valuable component of our coastal rainforests. This research has, for the most part, been published, is internationally recognized, and has been used as a textbook example of how an active tree breeding program can be used against an insect pest. Most of this work has been accomplished through the establishment, careful maintenance, and record keeping of well-replicated, long-term experimental plots. This effort has involved effective and skilled teams from the British Columbia Forest Service and the Canadian Forest Service, and collaboration with the forest industry and universities. Although an ongoing breeding program is planned through the establishment of F_1 trial series, it is unlikely to require the same intensive effort since the fundamental structure and populations capturing key resistance have been secured. Much of the effort in the future will likely be devoted to understanding the nature of this genetic resistance and better defining environmental hazards in order to adjust deployment guidelines. The results of this program are detailed and significant enough across the range of Sitka spruce in British Columbia that current recommendations are to deploy resistant provenances of Sitka spruce on suitable sites in the Coast Forest Region (Heppner and Turner 2006), including in-species admixtures where most of the block will be reforested to spruce. This will help increase diversity and bring back a historic species to the forests of British Columbia.

Alfaro, R.I. 1982. Fifty-year-old Sitka spruce plantations with a history of intense weevil attack. J. Entomol. Soc. B.C. 79:62–65.

_________. 1989. Probability of damage to Sitka spruce by the Sitka spruce weevil, *Pissodes strobi*. J. Entomol. Soc. B.C. 87:22–25.

_________. 1995. An induced defence reaction in white spruce to attack by white pine weevil. Can. J. For. Res. 25:1725–1730.

_________. 1996. Role of genetic resistance in managing ecosystems susceptible to white pine weevil. For. Chron. 72:374–380.

Alfaro, R.I., J.H. Borden, R.G. Fraser, and A.D. Yanchuk. 1994. The white pine weevil in British Columbia: basis for an integrated pest management system. For. Chron. 71:66–73.

Alfaro, R.I., J.H. Borden, J.N. King, E.S. Tomlin, R.L. McIntosh, and J. Bohlmann. 2002. Mechanisms of resistance in conifers against shoot infesting insects: the case of the white pine weevil *Pissodes strobi* (Peck) (Coleoptera: Curculionidae). In: Mechanisms and deployment of resistance in trees to insects. M.R. Wagner, K.M. Clancy, F. Lieutier, and T.D. Paine (editors). Klubbert Publ., Dordrecht, Netherlands, pp. 101–126.

Alfaro, R.I., F. He, G.K. Kiss, J. King, and A.D. Yanchuk. 1996. Resistance of white spruce to white pine weevil: development of a resistance index. For. Ecol. Manag. 81:51–62.

Alfaro, R.I., F. He, E. Tomlin, and G. Kiss. 1997. Resistance of white spruce to the white pine weevil related to resin canal density. Can. J. Bot. 75:568–573.

Alfaro, R.I., M.A. Hulme, and J.W.E. Harris. 1985. Insects associated with the Sitka spruce weevil, *Pissodes strobi* (Peck) (Coleoptera: Curculionidae) on Sitka spruce, *Picea sitchensis*, in British Columbia, Canada. Entomophaga 30:415–418.

Alfaro R.I, J.N. King, R.G. Brown, and S.M. Buddingh. 2008. Screening of Sitka spruce genotypes for resistance to the white pine weevil using artificial infestations. For. Ecol. Manag. 255:1749–1758.

Alfaro, R.I., J.N. King, Y.A. El-Kassaby, R.G. Brown, and K.G. Lewis. 2001. Use of artificial infestations in the selection of Sitka spruce genotypes for resistance to the white pine weevil in British Columbia, Canada. In: Proc. Protection of world forests from insect pests: advances in research. R.I. Alfaro, K. Day, S. Salom, K.S.S. Nair, H. Evans, A. Liebhold, F. Lieutier, M. Wagner, K. Futai, and K. Suzuki (editors.). XXI IUFRO World Congress, Kuala Lumpur, Malaysia. IUFRO, Vienna, Austria, pp. 13–18.

Alfaro, R.I., K.G. Lewis, J.N. King, Y.A. El-Kassaby, G. Brown, and L.D. Smith. 2000. Budburst phenology of Sitka spruce and its relationship to white pine weevil attack. For. Ecol. Manag. 127:19–29.

Alfaro, R.I. and S.A.Y. Omule. 1990. The effects of spacing on Sitka spruce weevil damage to Sitka spruce. Can. J. For. Res. 20:179–184.

Alfaro R.I., L. vanAkker, B. Jaquish, and J.N. King. 2004. Weevil resistance of progeny derived from putatively resistant and susceptible interior spruce parents. For. Ecol. Manag. 202:369–377.

Alfaro, R.I. and E. Wegwitz. 1994. The spruce weevil in the Green Timbers plantation. In: The white pine weevil: biology, damage and management. R.I. Alfaro, G. Kiss, and G. Fraser (editors). Can. For. Serv. and B.C. Min. For., Richmond, B.C. FRDA Rep. 226, pp. 222–225. www.for.gov.bc.ca/hfd/pubs/Docs/Frr/Frr226.htm

Alfaro, R.I. and C.C. Ying. 1990. Levels of Sitka spruce weevil, *Pissodes strobi* (Peck) damage among Sitka spruce provenances and families near Sayward, British Columbia (Canada). Can. Entomol. J. 122:607–616.

British Columbia Ministry of Forests and Range. 2008. 2007/08 annual service plan report. B.C. Min. For. Range, Victoria, B.C.

Carlquist, S. 1984. Wood and stem anatomy of Lardizabalaceae, with comments on vining habitat, ecology and systematics. Bot. J. Linn. Soc. 88:257–277.

Chakravarthy, A.K., A.S. Sidhu, and J. Singh. 1985. Effect of plant phenology and related factors on insect pest infestations in *Arboreum* and *Hirsutum* cotton varieties. Insect Sci. Appl. 6:521–532.

Daoust, G. and M.-J. Mottet. 2006. Impact of the white pine weevil (*Pissodes strobi* Peck) on Norway spruce plantations (*Picea abies* [L.] Karst.) Part 1: Productivity and lumber quality. For. Chron. 82:745–756.

Fernandes, G.W. and D. Negreiros. 2001. The occurrence and effectiveness of hypersensitive reaction against galling herbivores across host taxa. Ecol. Entomol. 26: 46–55.

Fletcher, A.M. 1976. Seed collection in north-west America with particular reference to a Sitka spruce seed collection for provenance studies. *In:* IUFRO Sitka spruce, *Picea sitchensis* (Bong.) Carr., international ten provenance experiment: nursery stage results. Forestry Commission, Edinburgh, Scotland, Bull. No. 17, pp. 2–20.

Fraser, R.G. and S. Szeto. 1994. Insecticides applied with Ezject will protect young Sitka spruce from white pine weevil attack. In: The white pine weevil: biology, damage and management. R.I. Alfaro, G. Kiss, and G. Fraser (editors). Can. For. Serv. and B.C. Min. For., Richmond, B.C. FRDA Rep. 226, pp. 229–247.

Gatehouse, J.A. 2002. Plant resistance towards insect herbivores: a dynamic interaction. New Phytol. 156:145–169.

Grau, M., R.I. Alfaro, and G. Brown. 2001. Bark traits related to resistance to the white pine weevil in selected Sitka spruce families. Can. For. Serv. and B.C. Min. For., Pacific Forestry Centre, Victoria, B.C. Unpubl. file rep.

Harris, M.O., T.P. Freeman, O. Rohrfritsch, K.G. Anderson, S.A. Payne, and J.A. Moore. 2006. Virulent Hessian fly (Diptera: Cecidomyiidae) larvae induce a nutritive tissue during compatible interactions with wheat. Ann. Entomol. Soc. Am. 99:305–316.

Harris, M.O., J.J. Stuart, M. Mohan, S. Nair, R.J. Lamb, and O. Rohrfritsch. 2003. Grasses and gall midges: plant defenses and insect adaptation. Annu. Rev. Entomol. 48:549–577.

Heppner, D. and J. Turner. 2006. British Columbia's coastal forests: spruce weevil and western spruce budworm forest health stand establishment decision aids. B.C. J. Ecosystems Manag. 7(3):45–49.

Hermann, R.K. 1987. North American tree species in Europe: transplanted species offer good growth potential on suitable sites. J. For. 85:27–32.

Huber, D.P.W., S. Ralph, and J. Bohlmann. 2004. Genomic hardwiring and phenotypic plasticity of terpenoid-based defenses in conifers. J. Chemical Ecol. 30:2399–2418.

Hulme, M.A. 1994. The potential of *Allodorus crassigaster* for the biological control of *Pissodes strobi*. In: The white pine weevil: biology, damage and management. R.I. Alfaro, G. Kiss, and G. Fraser (editors). Can. For. Serv. and B.C. Min. For., Richmond, B.C. FRDA Rep. 226, pp. 294–300. www.for.gov.bc.ca/hfd/pubs/Docs/Frr/Frr226.htm

__________. 1995. Resistance by translocated Sitka spruce to damage by *Pissodes strobi* (Coleoptera: Curculionidae) related to tree phenology. J. Econ. Entomol. 88:1525–1530.

Humble, L.M., N. Humphreys, and G.A. Van Sickle. 1994. Distribution and hosts of white pine weevil (*Pissodes strobi.*) in Canada. In: The white pine weevil: biology, damage and management. R.I. Alfaro, G. Kiss, and R.G. Fraser (editors). Can. For. Serv. and B.C. Min. For., Richmond, B.C. FRDA Rep. 226, pp. 68–75. www.for.gov.bc.ca/hfd/pubs/Docs/Frr/Frr226.htm

Illingworth, K. 1978. Study of lodgepole pine genotype-environment interaction in B.C. In: Douglas-fir provenances, lodgepole pine provenances, Sitka spruce provenances and *Abies* provenances: Proc. IUFRO Joint Meet. Work. Parties, Vancouver, B.C., pp. 151–158.

___________. 1980. Field experiments and performance of species: Sitka spruce. In: Proc. IUFRO Joint Meet. Work. Parties, 1978, Vancouver, B.C., B.C. Min. For., Info. Serv. Br., Victoria, B.C. 2:310–326.

King, J.N. 1994. Delivering durable resistant Sitka spruce for plantations. In: The white pine weevil: biology, damage and management. R.I. Alfaro, G. Kiss, and G. Fraser (editors). Can. For. Serv. and B.C. Min. For., Richmond, B.C. FRDA Rep. 226., pp. 134–149. www.for.gov.bc.ca/hfd/pubs/Docs/Frr/Frr226.htm

King, J.N. and R.I. Alfaro. 2001. Screening of Sitka spruce genotypes for resistance to the white pine weevil in British Columbia. In: Genetic response of forest systems to changing environmental conditions. G. Müller-Stark and R. Schubert (editors). Kluwer Academic Publ., Dordrecht, Netherlands, pp. 11–20.

___________. 2004. Breeding for resistance to a shoot weevil of Sitka spruce in British Columbia, Canada. *In:* Plantation forest biotechnology for the 21st century. C. Walter and M. Carson (editors). Research Signpost Publ., Kerala, India, pp.119–128.

King, J.N., R.I. Alfaro, and C. Cartwright. 2004. Genetic resistance of Sitka spruce (*Picea sitchensis*) populations to the white pine weevil (*Pissodes strobi*): distribution of resistance. Forestry 77:269–278.

King, J.N., A.D. Yanchuk, G.K. Kiss, and R.I. Alfaro. 1997. Genetic and phenotypic relationships between weevil resistance and height growth in spruce populations of British Columbia. Can. J. For. Res. 275:732–739.

Kiss, G.K. and A.D. Yanchuk. 1991. Preliminary evaluation of genetic variation of weevil resistance in interior spruce in British Columbia. Can. J. For. Res. 21:230–234.

Langor, D.W. and F.A.H. Sperling. 1995. Mitochondrial variation and identification of bark weevils in the *Pissodes strobi* species group in western Canada (Coleoptera: Curculionidae). Can. Entomol. 127:895–911.

Leal I., E.E. White, T.S. Sahota, and J.F. Manville. 1997. Differential gene expression of the vitellogenin gene in the spruce terminal weevil feeding on resistant versus susceptible trees. Insect Biochem. Mol. Biol. 27:569–575.

Maclauchlan, L.E. and J.H. Borden. 1994. Spatial attack dynamics and impact of *Pissodes terminalis* in three biogeoclimatic zones of southern B.C. In: The white pine weevil: biology, damage and management. R.I. Alfaro, G. Kiss, and G. Fraser (editors). Can. For. Serv. and B.C. Min. For., Richmond, B.C. FRDA Rep. 226, pp. 76–90. www.for.gov.bc.ca/hfd/pubs/Docs/Frr/Frr226.htm

McKay-Byun, A., K.-A. Godard, M. Toudefallah, D.M. Martin, R.I. Alfaro, J.N. King, J. Bohlmann, and A.L. Plant. 2006. Wound-induced terpene synthase gene expression in Sitka spruce that exhibit resistance or susceptibility to attack by the white pine weevil. Plant Physiol. 104:1009–1021.

McLean, A. 1994. Silvicultural control of the white pine weevil at the UBC Malcolm Knapp Research Forest. In: The white pine weevil: biology, damage and management. R.I. Alfaro, G. Kiss, and G. Fraser (editors). Can. For. Serv. and B.C. Min. For., Richmond, B.C. FRDA Rep. 226, pp. 248–253. www.for.gov.bc.ca/hfd/pubs/Docs/Frr/Frr226.htm

McMullen, L.H. 1976. Spruce weevil damage, ecological basis and hazard rating for Vancouver Island. Can. For. Serv. and B.C. Min. For., Pacific For. Cent., Victoria, B.C. Inf. Rep. BC-X-141.

Mitchell, R.G., K.H. Wright, and N.E. Johnson. 1990. Damage by the Sitka spruce weevil (*Pissodes strobi*) and growth patterns for 10 spruce species and hybrids over 26 years in the Pacific Northwest. USDA For. Serv., Pac. N.W. Res. Stn., Portland, Oreg. Res. Pap. PNW-RP-434.

O'Driscoll, J. 1976. International ten provenance experiment: working plan. In: IUFRO Sitka spruce, *Picea sitchensis* (Bong.) Carr., international ten provenance experiment: nursery stage results. Dep. Lands, For. and Wildl. Serv., Dublin, Ireland, pp. 140–163.

O'Neill, G.A., S.N. Aitken, J.N. King, and R.I. Alfaro. 2002. Geographic variation in resin canal defences in seedlings from the Sitka × white spruce introgression zone. Can. J. For. Res. 32:390–400.

Panda, N. and G.S. Khush. 1995. Host plant resistance to insects. CAB International, Oxon, U.K.

Rankin, L. and K.G. Lewis, 1994. Effectiveness of leader clipping for control of the white pine weevil, *Pissodes strobi*, in the Cariboo Forest Region of British Columbia. In: The white pine weevil: biology, damage and management. R.I. Alfaro, G. Kiss, and G. Fraser (editors). Can. For. Serv. and B.C. Min. For., Richmond, B.C. FRDA Rep. 226, pp. 262–269. www.for.gov.bc.ca/hfd/pubs/Docs/Frr/Frr226.htm

Sahota, T.S., J.F. Manville, J. Hollmann, I. Leal, A. Ibaraki, and E.E. White. 2001. Resistance against *Pissodes strobi* (Coleoptera: Curculionidae) in severed leaders and in water-soluble bark extract of *Picea sitchensis* (Pinaceae): evidence for a post-ingestive mode of action. Can. Entomol. 133:1–9.

Sahota, T.S., J.F. Manville, F.G. Peet, E.E. White, A.Ibaraki, and J.R. Nault. 1998. Resistance against white pine weevil: effects on weevil reproduction and host finding. Can. Entomol. 130:337–347.

Sahota, T.S., J.F. Manville, and E.E. White. 1994. Interaction between Sitka spruce weevil and its host *Picea sitchensis* (Bong) Carr.: a new mechanism for resistance. Can. Entomol. 126:1067–1074.

Samuel, C.J.A., A.M. Fletcher, and R. Lines. 2007. Choice of Sitka spruce seed origins for use in British forests. For. Comm. Bull. 127. For. Comm., Edinburgh, Scotland.

Spittlehouse, D.L., B.G. Sieben, and S.P. Taylor. 1994. Spruce weevil hazard mapping based on climate and ground survey data. In: The white pine weevil: biology, damage and management. R.I. Alfaro, G. Kiss, and G. Fraser (editors). Can. For. Serv. and B.C. Min. For., Richmond, B.C. FRDA Rep. 226, pp. 23–32. www.for.gov.bc.ca/hfd/pubs/Docs/Frr/Frr226.htm

Stoehr, M., J. Webber, and J. Woods. 2004. Protocol for rating seed orchard seedlots in British Columbia: quantifying genetic gain and diversity. Forestry 77:297–303.

Taylor, S.P., R.I. Alfaro, C. DeLong, and L. Rankin. 1996. The effects of overstory shading on white pine weevil damage to white spruce and its effect on spruce growth rates. Can. J. For. Res. 26:306–312.

Tomlin, E. and J.H. Borden. 1994. Relationship between leader morphology and resistance or susceptibility of Sitka spruce to the white pine weevil. Can. J. For. Res. 24:810–816.

White, T.L. and G.R. Hodge. 1989. Predicting breeding values with applications in forest tree improvement. Kluwer Academic Publishers. Dordrecht, Netherlands.

Xu, P., C.C. Ying, and Y.A. El-Kassaby. 2000. Multivariate approaches for determining the underlying major ecological factors characterizing growth of 43 Sitka spruce populations. Silvae Genet. 49:257–263.

Ying, C.C. 1991. Genetic resistance to the white pine weevil in Sitka spruce. B.C. Min. For., Victoria, B.C. Res. Note 196.

________. 1997. Effects of site, provenance and site interaction in Sitka spruce in coastal British Columbia. For. Genet. 4:99–112.

Ying, C.C. and T. Ebata. 1994. Provenance variation in weevil attack in Sitka spruce. In: The white pine weevil: biology, damage and management. R.I. Alfaro, G. Kiss, and G. Fraser (editors). Can. For. Serv. and B.C. Min. For., Richmond, B.C. FRDA Rep. 226, pp. 98–109. www.for.gov.bc.ca/hfd/pubs/Docs/Frr/Frr226.htm

GLOSSARY OF TERMS* USED IN THIS PUBLICATION

Avoidance	Mechanism by which negative effects are actively averted (e.g., insects preferring alternative hosts) (see Tolerance)
Bulk seedlot	A collection of seed pooled from different parents (families)
Bulk-up	Process by which plant material is vegetatively multiplied to increase numbers of individuals with the same genotype (clones)
Clone	noun: Individual plants produced asexually that all have the same genotype as the original plant. Most commonly used in forestry to establish grafted seed orchards but becoming more common for commercial plantations verb: To propagate a plant asexually usually by grafting, rooting cuttings, tissue culture, or apomictic seed to produce genetically identical copies
Constitutive trait	A trait that is always expressed (see Inducible)
Continuous trait	A quantitative trait with a distribution including a range of measured values, not discrete categories
Controlled cross	Pollination of specific female genotypes with selected male genotypes
Deployment	Strategy and implementation of installing improved trees across the landscape
Diallel	A controlled mating design resulting from crossing all male with all female parents; may or may not be a complete diallel (including self and reciprocal crosses)
Embling	A propagule created by somatic embryogenesis that is mature enough to plant (see Somatic Embryogenesis)
F_1	Controlled cross between two selected parents (first filial generation)
Full-sib (FS)	A family in which all offspring have the same pollen (paternal) and seed (maternal) parents
Genotype	An individual's assemblage of DNA, which includes genes and non-coding sequences

* Some definitions have been adapted from online sources, primarily including the Forest Genetics Council of British Columbia www.fgcouncil.bc.ca/doc-glos.html and C. Maynard's (SUNY) Forest Genetics Glossary www.esf.edu/for/maynard/GENE_GLOSSERY.html.

Half-sib (HS)	A family in which all offspring have either the same pollen (paternal) or seed (maternal) parent
Inducible trait	A trait that is expressed by an environmental trigger (see Constitutive)
Integrated pest management (IPM)	A means of managing forest health using the natural dynamics of indigenous insects, pathogens, and their hosts
IUFRO	International Union of Forest Research Organizations, "a non-profit, non-governmental international network of forest scientists"
Line	A group of offspring derived from a particular cross with a characteristic genotype or phenotype
Oocyte	Precursor to an egg cell, produced in the ovary
Open-pollinated (OP) family	A family in which all offspring have the same seed (maternal) parent but may have differing and unknown pollen (paternal) parents, possibly including some selfs
Ortet	The parent plant from which a (vegetative) clone is taken (see Ramet)
Oviposition	Insertion of a fertilized egg into an incubation chamber by an insect
Parasitoid	Specialized small insect who lives on a host (insect or mite) parasitically, eventually causing the death of the host
Phenology	The study of the phenomenon of biological developmental phases and rates (e.g., flowering time and duration)
Phenotype	Observable traits or characteristics of an individual, influenced in varying degrees by the genotype and environment
Plus-tree	A selected wild tree with desirable phenotypic traits
Progeny	Offspring of a given family that share one (open-pollinated or half-sib) or two (full-sib) parents
Progeny trial	Field test where offspring of particular parents are assessed; used to evaluate the performance of the parents (i.e., backward selection)
Provenance	Location of origin; seed source

Provenance trial	Field test where individuals or families from a range of populations and/or environmental conditions for various seed sources are assessed
Putative	Supposed or hypothesized
Ramet	A vegetatively reproduced copy of a plant; a clone (see Ortet)
Resin canal	An intercellular gap containing pitch (resin) secreted from surrounding cells
Resistance	The ability of an individual to withstand a particular stress
Sclereid cell	A dead cell that is a component of the sclerenchyma tissue with a lignified cell wall
Seed orchard	An intensively managed seed production area containing a plantation of selected individuals for the sole purpose of producing seed
Seedlot	Seeds collected from the same species, source, quality, and year of collection; may or may not be from the same family
Siblings (sibs)	Progeny who share at least one known parent
Somatic embryogenesis (SE)	A process by which embryos are vegetatively multiplied to produce many clones
Tolerance	Mechanism by which negative effects are withstood *in situ* (e.g., biochemical disease resistance) (see Avoidance)
Traumatic (resin canal)	Group of resin canals formed after exposure to stress (i.e., actual or simulated weevil feeding)
Vegetative propagation	Means by which an individual's genotype is reproduced without sexual reproduction (see Clone)

APPENDIX 1A Provenance Trials

Non-IUFRO Provenance Trials

EP 702.02

Year	Site code	Site name	Latitude (°N)	Longitude (°W)	Elevation (m)	BGC unit	Map grid
1973	A1	Area 1 QCI	53°33'	132°20'	460	CWHwh2	103F.115
1973	A2	Area 2 QCI	53°31'	132°11'	33	CWHwh1	103F.115
1973	A3	Area 3 QCI	53°24'	132°16'	85	CWHwh1	103F.115
1973	A4	Area 4 QCI	53°22'	132°16'	100	CWHwh1	103F.115
1973	A5	Area 5 QCI	53°08'	132°01'	450	CWHwh2	103F.115

EP 702.03

Year	Site code	Site name	Latitude (°N)	Longitude (°W)	Elevation (m)	BGC unit	Map grid
1974	1-SW	Sayward	50°13'	125°45'	75	CWHxm2	92K.106

IUFRO Trials

EP 702.04

Year	Site code	Site name	Latitude (°N)	Longitude (°W)	Elevation (m)	BGC unit	Map grid
1975	1-HG	Holberg (Vancouver Island)	50°44'	128°07'	60	CWHvh1	102I.120
1975	3-MN	Maroon Creek (Nass/Skeena)	54°46'	128°39'	600	CWHws2	103I.119
1975	4-NS	Nass River (Nass/Skeena)	55°04'	129°26'	15	CWHws1	103P.102
1975	5-DL	Dragon Lake (Nass/Skeena)	55°19'	128°58'	210	ICHmc2	103P.108

EP 702.05

Year	Site code	Site name	Latitude (°N)	Longitude (°W)	Elevation (m)	BGC unit	Map grid
1975	1-HB	Head Bay	49°48'	126°28'	15	CWHvm1	92E.124
1975	2-JU	Juskatla	53°34'	132°20'	20	CWHwh1	103F.115
1975	3-KT	Kitimat Valley	54°12'	128°33'	100	CWHws1	103I.104
1976	4-RS	Rennell Sound	53°23'	132°28'	50	CWHvh2	103F.109

APPENDIX 1B Clonal Trials—Weevil Screening

Clonal Trials—Weevil Screening

EP 702.06

Year	Site code	Site name	Latitude (°N)	Longitude (°W)	Elevation (m)	BGC unit	Map grid
1984	1-FH	Fair Harbour	50°04′	127°05′	20	CWHvm1	92L.103
1991	2-EC	Espinosa Creek	50°01′	126°57′	55	CWHvm1	92L.103
1992	3-GR	Glenroy Road	50°20′	125°55′	25	CWHxm2	92K.106
1992	4-AR	Armishaw Road	50°19′	125°55′	10	CWHxm2	92K.106
1992	5-SC	Sandcut Creek (Jordan River)	48°24′	123°59′	60	CWHxm2	92B.111
1997	6-MB	Menzies Bay	50°07′	125°23′	60	CWHxm1	92K.102

Embling Trials

EP 702.07

Year	Site code	Site name	Latitude (°N)	Longitude (°W)	Elevation (m)	BGC unit	Map grid
2000	1-FC	French Creek 2 (Vancouver Isl.)	49°17′	124°29′	190	CWHxm1	92F.109
2000	2-VM	Varney Main	50°34′	127°24′	90	CWHvm1	92L.112
2000	3-B6	Copper Bay 1	53°12′	131°47′	23	CWHwh1	103G.101
2000	4-KI	Knight Inlet 2	51°10′	125°38′	50	CWHvm1	92N.101

APPENDIX 1C OP Progeny Trials—Weevil Screening

Weevil Screening Progeny Test Sites

EP 702.08.01-JR—Jordan River series

Year	Site code	Site name	Latitude (°N)	Longitude (°W)	Elevation (m)	BGC unit	Map grid
1992	1-JR	Jordan River (southwest Vancouver Island)	48°25′	124°01′	75	CWHvm1	92C.115
1992	2-NA	North Arm (Cowichan Lake)	48°50′	124°06′	175	CWHxm2	92C.125
1992	3-SK	Skowkona (QCI)	53°19′	132°09′	480	CWHwh2	103F.110
1992	5-JM	Moclips River (Wash.)	47°17′	124°06′	80	na	na
1992	6-BO	Dowans Cr. (Rayonier Ltd. Wash.)	47°21′	124°18′	90	na	na
1994	7-HA	Hamlet (Astoria District Oreg.)	45°51′	123°44′	240	na	na
1994	8-SC	South Coal (Oreg.)	45°45′	123°51′	60	na	na

EP 702.08.02-PR—Port Renfrew series

Year	Site code	Site name	Latitude (°N)	Longitude (°W)	Elevation (m)	BGC unit	Map grid
1994	1-RF	Renfrew flat site	48°36′	124°23′	100	CWHvm1	92C.120
1994	2-RS	Renfrew steep site	48°36′	124°25′	210	CWHvm1	92C.119
1994	3-SN	Snowdon Forest	50°04′	125°21′	85	CWHxm1	92K.102
1994	4-DN	Deena QCI	53°07′	132°14′	110	CWHwh1	103F.105
1994	5-QR	Quinault River, Wash.	47°24′	123°55′	90	na	na
1994	6-FO	Forks Rayonier Ltd., Wash.	47°58′	124°28′	100	na	na

EP 702.08.03-C4—Camp 4 series

Year	Site code	Site name	Latitude (°N)	Longitude (°W)	Elevation (m)	BGC unit	Map grid
1995	1-C4	Camp 4	50°05′	125°22′	55	CWHxm1	92K.102
1995	2-DR	Derby	50°25′	126°34′	175	CWHvm1	92L.114
1995	3-VC	Victoria Lake	50°21′	127°22′	150	CWHvm1	92L.107
1995	4-SP	Spectacular Gorge (QCI)	53°06′	132°09′	170	CWHwh1	103F.105

EP 702.08.04-CO—Coombs series

Year	Site code	Site name	Latitude (°N)	Longitude (°W)	Elevation (m)	BGC unit	Map grid
1999	1-CO	Coombs Pub	49°18′	124°25′	100	CDFmm	92F.109
1999	2-HM	Harrison Mills	49°14′	122°01′	170	CWHdm	92G.110
1999	3-WC	Waterfall Creek (QCI)	53°33′	132°34′	340	CWHwh1	103F.114

EP 702.08.05-PI—Pigott series

Year	Site code	Site name	Latitude (°N)	Longitude (°W)	Elevation (m)	BGC unit	Map grid
2007	1-HR	Hathaway River	50°35′	127°46′	10	CWHvm1	92L.111
2007	2-KC	Harrison Mills	50°27′	127°42′	100	CWHvm1	92L.111

APPENDIX 1D OP Progeny Trials—QCI and Others

EP 702.09 UK 1997—U.K. Forestry Commission Spruce 1997

Year	Site code	Site name	Latitude (°N)	Longitude (°W)	Elevation (m)	BGC unit	Map grid
1997	01-HS	Hoiss	49°42′	126°33′	20	CWHvh1	92E.119
1997	02-RN	Bonanza Creek (Rennell, QCI)	53°26′	132°32′	60	CWHvh1	103F.114
1997	03-GD	Gold Creek	53°28′	132°19′	275	CWHvh1	103F.115

EP 702.09 UK 2000—U.K. Forestry Commission Spruce 2000

Year	Site code	Site name	Latitude (°N)	Longitude (°W)	Elevation (m)	BGC unit	Map grid
2000	04-CB2	Copper Bay 2 QCI	53°11′	131°47′	21	CWHwh1	103G.101
2000	05-SKL	Skidegate Lake QCI	53°07′	131°52′	82	CWHwh1	103G.101
2000	06-BBC	Bill Brown Creek	53°26′	132°35′	91	CWHvh2	103F.114

EP 702.12—High-elevation trials

Year	Site code	Site name	Latitude (°N)	Longitude (°W)	Elevation (m)	BGC unit	Map grid
2006	01-NF	North Fork	48°48′	124°49′	540	CWHvm1	92C.123
2006	02-SC	Saunders Creek	49°51′	126°03′	650	CWHvm2	92E.125

APPENDIX 1E F_1 Trial Series

EP 702.10—Full-sib Crossing Trials

Year	Site code	Site name	Latitude (°N)	Longitude (°W)	Elevation (m)	BGC unit	Map grid
2004	01-JM-I	Jordan River Main	48°27′	124°04′	270	CWHvm1	92C.115
2004	02-LA-I	Lower Adam River	50°28′	126°16′	20	CWHvm1	92L.115
2005	03-GB24-I	Gray Bay 24	53°06′	131°51′	150	CWHwh1	103G.101
2006	04-IC-II	Ingersol Creek	50°28′	127°41′	100	CWHvm1	92L.111
2006	05-CC-II	Coetkwaus Creek	50°34′	127°24′	80	CWHvm1	92L.112
2006	06-GB31-II	Gray Bay 31	53°06′	131050′	135	CWHwh1	103G.101
2008	07-FR-III	Forebay Road	48°26′	124°01′	280	CWHvm1	92G.115
2008	08-PC-III	Pinch Creek	50°26′	127°22′	170	CWHvm1	92L.112
2008	09-C27-III	Copper 27	53°08′	131°49′	100	CWHwh1	103G.101

APPENDIX 1F Demonstration, Silviculture Interaction, and Hazard Evaluation Trials

EP 702.00.01—Silvicultural Trials

Year	Site code	Site name	Latitude (°N)	Longitude (°W)	Elevation (m)	BGC unit	Map grid
1991	1-NI	Nimpkish (CFS Trial)	50°19′	126°54′	40	CWHxm2	92L.108
1994	2-ER	Eve River	50°17′	126°18′	370	CWHvm1	92L.110
1995	3-HS	Hisnit	49°47′	126°29′	30	CWHvm1	92E.119
1998	4-KT	Kettle	50°00′	126°18′	300	CWHxm2	92L.105
2000	05-FC	French Creek 1	49°17′	124°29′	190	CWHxm1	92F.109
2000	06-KI	Knight Inlet 3	51°10′	125°36′	50	CWHvm1	92N.101

EP 702.00.02—Hazard Index Trials

Year	Site code	Site name	Latitude (°N)	Longitude (°W)	Elevation (m)	BGC unit	Map grid
1999	5-EH	Errington High	49°15′	124°24′	230	CWHxm1	92F.109
1999	6-AR	Adam River	50°27′	126°11′	80	CWHvm1	92L.115
1999	7-KI	Knight Inlet 1	51°08′	125°36′	50	CWHvm1	92N.101
1999	8-MP	Michelson Point	50°35′	127°42′	100	CWHvm1	92L.111
1999	9-KL	Klanawa	48°45′	124°50′	68	CWHvm1	92C.123
1999	10-UH	Upper Harrison (Mt. Woodside)	49°15′	121°54′	580	CWHdm	92H.106
1999	11-CC	Cala Creek	49°48′	126°12′	570	CWHvm2	92E.120
2000	12-NC	Nadina Creek	54°17′	128°28′	292	CWHws1	103I.109

EP 702.11—Demonstration Trials

Year	Site code	Site name	Latitude (°N)	Longitude (°W)	Elevation (m)	BGC unit	Map grid
1993	n.a.	CLRS spruce species	48°49'	124°08'	188	CWHxm2	92C.125
1995	n.a.	CLRS Ss provenance	48°49'	124°08'	188	CWHxm2	92C.125
1995	n.a.	Hisnit (CFS Trial)	49°47'	126°29'	30	CWHvm1	92E.119
1996	n.a.	CLRS seedling & embling	48°49'	124°08'	188	CWHxm2	92C.125
1998	n.a.	Jordan River demonstration	48°24'	123°59'	115	CWHxm2	92C.115
1999	n.a.	CLRS demonstration	48°49'	124°08'	188	CWHxm2	92C.125
1998	01-WC	Waukwaas Creek	50°34'	127°24'	100	CWHvm1	92L.112
1999	03-CM	Coombs	49°18'	124°26'	100	CDFmm	92F.109
2001	02-CR	Clark Road	48°23'	123°50'	60	CWHxm2	92B.106
2003	04-WN	Wanokana	50°37'	127°42'	110	CWHvm1	92L.116
2003	05-MR	Marble River	50°32'	127°26'	90	CWHvm1	92L.112
2003	06-BC	Bish Creek	53°55'	128°48'	140	CWHvm	103H.124

NOTE: n.a. = not assigned EP registration

APPENDIX 1G Sitka Spruce Hybrid Trials

EP 1072.00

Year	Site code	Site name	Latitude (°N)	Longitude (°W)	Elevation (m)	BGC unit	Map grid
2000	1-CC	Chist Creek (Nass/Skeena)	54°18'	128°27'	280	CWHws1	103I.109
2000	2-DM	Darling Mills (Nass/Skeena)	55°09'	128°04'	470	ICHmc2	103P.105
2000	3-DB	Deuce Branch (Nass/Skeena)	55°18'	128°10'	735	CWHws2	103P.110
2000	4-DC	Douglas Creek (Nass/Skeena)	54°53'	128°45'	995	CWHws2	103I.124
2000	5-HF	Harper FSR (Nass/Skeena)	55°41'	128°48'	235	ICHmc1	103P.119
2000	6-HL	Helen Lake (Nass/Skeena)	55°30'	127°59'	800	ICHmc1	93M.111
2000	7-MD	McDonnel Lake (Nass/Skeena)	54°48'	127°49'	868	ICHmc1	93L.121
2000	8-RC	Rutherford Creek (Nass/Skeena)	50°18'	123°03'	840	CWHms1	92J.108
2000	9-SC	Sterling Creek (Nass/Skeena)	54°60'	128°53'	650	CWHws2	103I.123
2000	10-WB	Whitebottom (Nass/Skeena)	54°23'	128°51'	250	CWHws1	103I.108
1988	11-LO	Littleoliver	54°47'	128°17'	140	ICHmc2	103I.120
1988	12-SU	Suskwa	55°12'	127°22'	350	ICHmc2	93M.102

EP 1072.10—Engelmann Spruce Trials

Year	Site code	Site name	Latitude (°N)	Longitude (°W)	Elevation (m)	BGC unit	Map grid
2001	01	Garnet Creek	49°29'	121°37'	960	MHmm1	92H.111
2001	02	South Ainslie Creek	49°57'	121°22'	1150	ESSFmv	92H.122

APPENDIX 2 Sources of Parent Trees in Screening Trials

APPENDIX 2A Source of Parent Trees: EP 702.06—Clonal Series

Registration No.	Source	Latitude (°N)	Longitude (°W)	Elevation (m)	BGC unit	Trials
847	Big Qualicum River	49°24'	124°37'	5	CDFmm	AR
848	Big Qualicum River	49°24'	124°37'	5	CDFmm	AR
849	Big Qualicum River	49°24'	124°37'	5	CDFmm	AR
850	Big Qualicum River	49°24'	124°37'	5	CDFmm	AR
851	Big Qualicum River	49°24'	124°37'	5	CDFmm	AR
852	Big Qualicum River	49°24'	124°37'	5	CDFmm	AR
855	Big Qualicum River	49°24'	124°37'	5	CDFmm	AR
856	Big Qualicum River	49°24'	124°37'	5	CDFmm	AR
857	Big Qualicum River	49°24'	124°37'	5	CDFmm	AR
858	Big Qualicum River	49°24'	124°37'	5	CDFmm	AR
859	Big Qualicum River	49°24'	124°37'	5	CDFmm	AR
860	Big Qualicum River	49°24'	124°37'	5	CDFmm	AR
861	Big Qualicum River	49°24'	124°37'	5	CDFmm	AR
862	Big Qualicum River	49°24'	124°37'	5	CDFmm	AR
863	Big Qualicum River	49°24'	124°37'	5	CDFmm	AR
864	Big Qualicum River	49°24'	124°37'	5	CDFmm	AR
865	Big Qualicum River	49°24'	124°37'	5	CDFmm	AR
866	Big Qualicum River	49°24'	124°37'	5	CDFmm	AR
867	Big Qualicum River	49°24'	124°37'	5	CDFmm	AR
868	Big Qualicum River	49°24'	124°37'	5	CDFmm	AR
869	Big Qualicum River	49°24'	124°37'	5	CDFmm	AR
870	Big Qualicum River	49°24'	124°37'	5	CDFmm	AR
871	Big Qualicum River	49°24'	124°37'	5	CDFmm	AR
872	Big Qualicum River	49°24'	124°37'	5	CDFmm	GR
873	Big Qualicum River	49°24'	124°37'	5	CDFmm	AR
874	Big Qualicum River	49°24'	124°37'	5	CDFmm	AR
875	Big Qualicum River	49°24'	124°37'	5	CDFmm	AR
876	Big Qualicum River	49°24'	124°37'	5	CDFmm	AR
877	Squamish River	49°53'	123°15'	30	CWHdm	EC
878	Squamish River	49°53'	123°15'	30	CWHdm	AR
879	Big Qualicum River	49°24'	124°37'	5	CDFmm	EC
880	Big Qualicum River	49°24'	124°37'	5	CDFmm	EC
881	Big Qualicum River	49°24'	124°37'	5	CDFmm	EC
882	Big Qualicum River	49°24'	124°37'	5	CDFmm	EC
883	Big Qualicum River	49°24'	124°37'	5	CDFmm	EC
884	Big Qualicum River	49°24'	124°37'	5	CDFmm	EC
885	Wedeene River	54°08'	128°37'	165	CWHvm	EC
886	Wedeene River	54°08'	128°37'	165	CWHvm	EC
887	Derrick Lake	55°41'	128°41'	240	ICHmc1	EC
888	Cedarvale	55°01'	128°19'	240	ICHmc2	EC
889	Haney	49°14'	122°36'	195	CWHdm	EC
890	Haney	49°14'	122°36'	195	CWHdm	EC
891	Haney	49°14'	122°36'	195	CWHdm	EC
892	Haney	49°14'	122°36'	195	CWHdm	EC
893	Haney	49°14'	122°36'	195	CWHdm	EC
894	Haney	49°14'	122°36'	195	CWHdm	EC
895	Haney	49°14'	122°36'	195	CWHdm	EC
896	Haney	49°14'	122°36'	195	CWHdm	EC
897	Haney	49°14'	122°36'	195	CWHdm	EC
898	Haney	49°14'	122°36'	195	CWHdm	EC FH
899	Big Qualicum River	49°24'	124°37'	5	CDFmm	EC
900	Haney	49°14'	122°36'	150	CWHdm	GR
901	Blenheim Mountain	48°54'	124°57'	210	CWHvm1	EC

Appendix 2A *Continued*

Registration No.	Source	Latitude (°N)	Longitude (°W)	Elevation (m)	BGC unit	Trials
902	Blenheim Mountain	48°54'	124°57'	210	CWHvm1	EC
903	Masset Sound	53°55'	132°05'	5	CWHwh1	EC
904	Malcolm Knapp	49°16'	122°34'	136	CWHdm	AR
905	Malcolm Knapp	49°16'	122°34'	136	CWHdm	EC
906	Malcolm Knapp	49°16'	122°34'	136	CWHdm	EC
907	Malcolm Knapp	49°16'	122°34'	138	CWHdm	AR
908	Malcolm Knapp	49°16'	122°34'	137	CWHdm	EC
909	Malcolm Knapp	49°16'	122°34'	139	CWHdm	EC
910	Malcolm Knapp	49°16'	122°34'	138	CWHdm	EC
911	Malcolm Knapp	49°16'	122°34'	137	CWHdm	EC
912	Malcolm Knapp	49°15'	122°34'	133	CWHdm	EC
913	Malcolm Knapp	49°15'	122°34'	134	CWHdm	EC
914	Malcolm Knapp	49°15'	122°34'	135	CWHdm	EC
915	Malcolm Knapp	49°15'	122°34'	135	CWHdm	AR
916	Malcolm Knapp	49°15'	122°34'	133	CWHdm	AR
917	Malcolm Knapp	49°15'	122°34'	134	CWHdm	GR
918	Malcolm Knapp	49°15'	122°34'	135	CWHdm	EC
919	Maple Ridge	49°14'	122°35'	15	CWHdm	EC
920	Maple Ridge	49°14'	122°35'	15	CWHdm	EC
921	Maple Ridge	49°14'	122°35'	15	CWHdm	EC
922	Maple Ridge	49°14'	122°35'	15	CWHdm	AR
923	Maple Ridge	49°14'	122°35'	15	CWHdm	GR
924	Maple Ridge	49°14'	122°35'	15	CWHdm	EC
925	Maple Ridge	49°14'	122°35'	15	CWHdm	GR
926	Maple Ridge	49°14'	122°35'	15	CWHdm	GR
927	Maple Ridge	49°14'	122°35'	15	CWHdm	EC
928	Maple Ridge	49°14'	122°35'	15	CWHdm	EC
930	Maple Ridge	49°14'	122°35'	15	CWHdm	EC
931	Maple Ridge	49°14'	122°35'	15	CWHdm	AR
932	Big Qualicum River	49°24'	124°37'	5	CDFmm	EC
933	Big Qualicum River	49°24'	124°37'	5	CDFmm	EC
934	Big Qualicum River	49°24'	124°37'	5	CDFmm	EC
935	Big Qualicum River	49°24'	124°37'	5	CDFmm	EC
936	Big Qualicum River	49°24'	124°37'	5	CDFmm	EC
937	Big Qualicum River	49°24'	124°37'	5	CDFmm	EC
938	Big Qualicum River	49°24'	124°37'	5	CDFmm	EC
939	Big Qualicum River	49°24'	124°37'	5	CDFmm	EC
940	Big Qualicum River	49°24'	124°37'	5	CDFmm	EC
942	Kitwanga	55°10'	127°52'	660	ICHmc2	EC
943	Kitwanga	55°10'	127°52'	660	ICHmc2	EC
944	Kitwanga	55°10'	127°52'	660	ICHmc2	EC
945	Kitwanga	55°10'	127°52'	660	ICHmc2	EC
946	Big Qualicum River	49°24'	124°37'	5	CDFmm	EC
947	Big Qualicum River	49°24'	124°37'	5	CDFmm	EC
948	Big Qualicum River	49°24'	124°37'	5	CDFmm	AR
949	Big Qualicum River	49°24'	124°37'	5	CDFmm	EC
950	Big Qualicum River	49°24'	124°37'	5	CDFmm	AR
951	Big Qualicum River	49°24'	124°37'	5	CDFmm	EC
952	Usk Ferry	54°38'	128°24'	135	CWHws1	EC
953	Usk Ferry	54°38'	128°24'	135	CWHws1	EC
954	Usk Ferry	54°38'	128°24'	135	CWHws1	EC
955	Big Qualicum River	49°24'	124°37'	5	CDFmm	EC
956	Big Qualicum River	49°24'	124°37'	5	CDFmm	EC
957	Big Qualicum River	49°24'	124°37'	5	CDFmm	EC
958	Big Qualicum River	49°24'	124°37'	5	CDFmm	EC

Appendix 2A ***Continued***

Registration No.	Source	Latitude (°N)	Longitude (°W)	Elevation (m)	BGC unit	Trials
959	Big Qualicum River	49°24'	124°37'	5	CDFmm	EC
960	Big Qualicum River	49°24'	124°37'	5	CDFmm	EC
962	Big Qualicum River	49°24'	124°37'	5	CDFmm	EC
963	Big Qualicum River	49°24'	124°37'	5	CDFmm	GR
964	Big Qualicum River	49°24'	124°37'	5	CDFmm	EC
1037	Usk Ferry	54°38'	128°24'	135	CWHws1	GR
1038	Big Qualicum River	49°24'	124°37'	5	CDFmm	EC
1039	Big Qualicum River	49°24'	124°37'	5	CDFmm	EC
1040	Big Qualicum River	49°24'	124°37'	5	CDFmm	EC
1041	Forks	48°04'	124°18'	135	na	EC
1042	Big Qualicum River	49°24'	124°37'	5	CDFmm	EC
1043	Big Qualicum River	49°24'	124°37'	5	CDFmm	EC
1044	Big Qualicum River	49°24'	124°37'	5	CDFmm	EC
1045	Big Qualicum River	49°24'	124°37'	5	CDFmm	EC
1046	Big Qualicum River	49°24'	124°37'	5	CDFmm	EC
1047	Big Qualicum River	49°24'	124°37'	5	CDFmm	EC
1048	Forks	48°04'	124°18'	135	na	EC
1049	Usk Ferry	54°38'	128°24'	135	CWHws1	EC
1050	Hoquiam	47°05'	124°03'	5	na	EC
1051	Forks	48°04'	124°18'	135	na	EC
1052	Squamish River	49°53'	123°15'	30	CWHdm	EC
1053	Cedarvale	55°01'	128°19'	240	ICHmc2	EC
1054	Big Qualicum River	49°24'	124°37'	5	CDFmm	EC
1055	Derrick Lake	55°41'	128°41'	240	ICHmc1	EC
1056	Haney	49°14'	122°36'	150	CWHdm	EC FH
1057	Fair Harbour	50°03'	127°02'	30	CWHvm1	EC
1058	Usk Ferry	54°38'	128°24'	135	CWHws1	EC
1059	Haney	49°14'	122°36'	150	CWHdm	EC FH
1060	Big Qualicum River	49°24'	124°37'	5	CDFmm	EC
1061	Big Qualicum River	49°24'	124°37'	5	CDFmm	EC
1062	Squamish River	49°53'	123°15'	30	CWHdm	EC
1063	Dragon Lake	55°21'	128°57'	255	ICHmc1	EC
1064	Fair Harbour	50°03'	127°02'	30	CWHvm1	EC
1065	Squamish River	49°53'	123°15'	30	CWHdm	EC
1066	Cranberry River	55°28'	128°14'	510	ICHmc2	EC
1067	Big Qualicum River	49°24'	124°37'	5	CDFmm	EC
1068	Big Qualicum River	49°24'	124°37'	5	CDFmm	EC
1069	Squamish River	49°53'	123°15'	30	CWHdm	EC
1070	Derrick Lake	55°41'	128°41'	240	ICHmc1	EC
1071	Big Qualicum River	49°24'	124°37'	5	CDFmm	EC
1072	Haney	49°14'	122°36'	150	CWHdm	EC
1073	Big Qualicum River	49°24'	124°37'	5	CDFmm	EC
1074	Big Qualicum River	49°24'	124°37'	5	CDFmm	EC
1075	Haney	49°14'	122°36'	150	CWHdm	EC
1076	Squamish River	49°53'	123°15'	30	CWHdm	EC
1077	Derrick Lake	55°41'	128°41'	240	ICHmc1	EC
1078	Haney	49°14'	122°36'	150	CWHdm	EC
1079	Haney	49°14'	122°36'	150	CWHdm	EC
1080	Haney	49°14'	122°36'	150	CWHdm	EC
1081	Big Qualicum River	49°24'	124°37'	5	CDFmm	EC
1082	Big Qualicum River	49°24'	124°37'	5	CDFmm	EC
1083	Big Qualicum River	49°24'	124°37'	5	CDFmm	EC
1084	Haney	49°14'	122°36'	150	CWHdm	EC
1085	Kitwanga	55°10'	127°52'	660	ICHmc2	EC
1086	Haney	49°14'	122°36'	150	CWHdm	EC

Appendix 2A ***Continued***

Registration No.	Source	Latitude (°N)	Longitude (°W)	Elevation (m)	BGC unit	Trials
1087	Squamish River	49°53'	123°15'	30	CWHdm	EC
1088	Usk Ferry	54°38'	128°24'	135	CWHws1	EC
1089	Haney	49°14'	122°36'	150	CWHdm	EC
1090	Haney	49°14'	122°36'	150	CWHdm	EC
1091	Squamish River	49°53'	123°15'	30	CWHdm	GR
1092	Haney	49°14'	122°36'	150	CWHdm	EC
1093	Haney	49°14'	122°36'	150	CWHdm	EC
1094	Wedeene River	54°08'	128°37'	165	CWHvm	GR
1095	Haney	49°14'	122°36'	150	CWHdm	EC
1096	Big Qualicum River	49°24'	124°37'	5	CDFmm	EC
1097	Big Qualicum River	49°24'	124°37'	5	CDFmm	EC
1098	Big Qualicum River	49°24'	124°37'	5	CDFmm	EC
1099	Big Qualicum River	49°24'	124°37'	5	CDFmm	EC
1100	Big Qualicum River	49°24'	124°37'	5	CDFmm	EC
1101	Big Qualicum River	49°24'	124°37'	5	CDFmm	EC
1102	Upper Squamish Valley	49°53'	125°15'	22	CWHxm1	GR
1103	Upper Squamish Valley	49°53'	125°15'	22	CWHxm1	GR
1104	Upper Squamish Valley	49°53'	125°15'	22	CWHxm1	GR
1105	Upper Squamish Valley	49°53'	125°15'	22	CWHxm1	GR
1106	Upper Squamish Valley	49°53'	125°15'	22	CWHxm1	AR
1107	Upper Squamish Valley	49°53'	125°15'	22	CWHxm1	GR
1108	Upper Squamish Valley	49°53'	125°15'	22	CWHxm1	GR
1109	Upper Squamish Valley	49°53'	125°15'	22	CWHxm1	GR
1110	Upper Squamish Valley	49°53'	125°15'	22	CWHxm1	GR
1111	Upper Squamish Valley	49°53'	125°15'	22	CWHxm1	GR
1112	Upper Squamish Valley	49°53'	125°15'	22	CWHxm1	GR
1113	Upper Squamish Valley	49°53'	125°15'	22	CWHxm1	GR
1114	Upper Squamish Valley	49°53'	125°15'	22	CWHxm1	GR
1115	Upper Squamish Valley	49°53'	125°15'	22	CWHxm1	GR
1116	Upper Squamish Valley	49°53'	125°15'	22	CWHxm1	AR
1117	Upper Squamish Valley	49°53'	125°15'	22	CWHxm1	GR
1118	Upper Squamish Valley	49°53'	125°15'	22	CWHxm1	GR
1119	Upper Squamish Valley	49°53'	125°15'	22	CWHxm1	GR
1120	Upper Squamish Valley	49°53'	125°15'	22	CWHxm1	GR
1121	Upper Squamish Valley	49°53'	125°15'	22	CWHxm1	GR
1122	Upper Squamish Valley	49°53'	125°15'	22	CWHxm1	GR
1123	Upper Squamish Valley	49°53'	125°15'	22	CWHxm1	GR
1124	Upper Squamish Valley	49°53'	125°15'	22	CWHxm1	GR
1125	Upper Squamish Valley	49°53'	125°15'	22	CWHxm1	GR
1126	Upper Squamish Valley	49°53'	125°15'	22	CWHxm1	GR
1127	Upper Squamish Valley	49°53'	125°15'	22	CWHxm1	GR
1128	Upper Squamish Valley	49°53'	125°15'	22	CWHxm1	GR
1129	Upper Squamish Valley	49°53'	125°15'	22	CWHxm1	GR
1130	Upper Squamish Valley	49°53'	125°15'	22	CWHxm1	GR
1131	Upper Squamish Valley	49°53'	125°15'	22	CWHxm1	GR
1132	Upper Squamish Valley	49°53'	125°15'	22	CWHxm1	GR
1133	Upper Squamish Valley	49°53'	125°15'	22	CWHxm1	GR
1134	Upper Squamish Valley	49°53'	125°15'	22	CWHxm1	EC
1135	Upper Squamish Valley	49°53'	125°15'	22	CWHxm1	GR
1136	Upper Squamish Valley	49°53'	125°15'	22	CWHxm1	GR
1137	Upper Squamish Valley	49°53'	125°15'	22	CWHxm1	GR
1138	Upper Squamish Valley	49°53'	125°15'	22	CWHxm1	GR
1139	Kanaka Creek	49°12'	122°33'	12	CWHxm1	AR
1140	Kanaka Creek	49°12'	122°33'	12	CWHxm1	AR
1141	Kanaka Creek	49°12'	122°33'	12	CWHxm1	na
1142	Kanaka Creek	49°12'	122°33'	12	CWHxm1	GR

Appendix 2A *Continued*

Registration No.	Source	Latitude (°N)	Longitude (°W)	Elevation (m)	BGC unit	Trials
1143	Kanaka Creek	49°12'	122°33'	12	CWHxm1	na
1144	Kanaka Creek	49°12'	122°33'	12	CWHxm1	AR
1145	Kanaka Creek	49°12'	122°33'	12	CWHxm1	na
1146	Kanaka Creek	49°12'	122°33'	12	CWHxm1	GR
1147	Kanaka Creek	49°12'	122°33'	12	CWHxm1	EC
1148	Kanaka Creek	49°12'	122°33'	12	CWHxm1	GR
1149	Kanaka Creek	49°12'	122°33'	12	CWHxm1	GR
1150	Kanaka Creek	49°12'	122°33'	12	CWHxm1	AR
1151	Kanaka Creek	49°12'	122°33'	12	CWHxm1	GR
1152	Kanaka Creek	49°12'	122°33'	12	CWHxm1	AR
1153	Kanaka Creek	49°12'	122°33'	12	CWHxm1	AR
1154	Kanaka Creek	49°12'	122°33'	12	CWHxm1	AR
1155	Kanaka Creek	49°12'	122°33'	12	CWHxm1	na
1156	Kanaka Creek	49°12'	122°33'	12	CWHxm1	GR
1157	Kanaka Creek	49°12'	122°33'	12	CWHxm1	na
1158	Kanaka Creek	49°12'	122°33'	12	CWHxm1	AR
1159	Kanaka Creek	49°12'	122°33'	12	CWHxm1	GR
1160	Kanaka Creek	49°12'	122°33'	12	CWHxm1	GR
1161	Kanaka Creek	49°12'	122°33'	12	CWHxm1	GR
1162	Kanaka Creek	49°12'	122°33'	12	CWHxm1	GR
1163	Kanaka Creek	49°12'	122°33'	12	CWHxm1	GR
1164	Kanaka Creek	49°12'	122°33'	12	CWHxm1	GR
1165	Kanaka Creek	49°12'	122°33'	12	CWHxm1	EC
1166	Kanaka Creek	49°12'	122°33'	12	CWHxm1	GR
1167	Kanaka Creek	49°12'	122°33'	12	CWHxm1	GR
1168	Kanaka Creek	49°12'	122°33'	12	CWHxm1	AR
1169	Kanaka Creek	49°12'	122°33'	12	CWHxm1	GR
1170	Kanaka Creek	49°12'	122°33'	12	CWHxm1	GR
1171	Kanaka Creek	49°12'	122°33'	12	CWHxm1	GR
1172	Kanaka Creek	49°12'	122°33'	12	CWHxm1	GR
1173	Kanaka Creek	49°12'	122°33'	12	CWHxm1	GR
1174	Kanaka Creek	49°12'	122°33'	12	CWHxm1	GR
1175	Kanaka Creek	49°12'	122°33'	12	CWHxm1	GR
1176	Kanaka Creek	49°12'	122°33'	12	CWHxm1	EC
1177	Kanaka Creek	49°12'	122°33'	12	CWHxm1	AR
1178	Kanaka Creek	49°12'	122°33'	12	CWHxm1	GR
1179	Kanaka Creek	49°12'	122°33'	12	CWHxm1	GR
1180	Kanaka Creek	49°12'	122°33'	12	CWHxm1	GR
1181	Kanaka Creek	49°12'	122°33'	12	CWHxm1	GR
1182	Kanaka Creek	49°12'	122°33'	12	CWHxm1	GR
1183	Kanaka Creek	49°12'	122°33'	12	CWHxm1	GR
1184	Kanaka Creek	49°12'	122°33'	12	CWHxm1	GR
1185	Kanaka Creek	49°12'	122°33'	12	CWHxm1	AR
1186	Kanaka Creek	49°12'	122°33'	12	CWHxm1	GR
1187	Kanaka Creek	49°12'	122°33'	12	CWHxm1	GR
1188	Kanaka Creek	49°12'	122°33'	12	CWHxm1	GR
1189	Kanaka Creek	49°12'	122°33'	12	CWHxm1	GR
1208	Haney	49°14'	122°36'	150	CWHdm	AR
1209	Haney	49°14'	122°36'	150	CWHdm	AR
1210	Haney	49°14'	122°36'	150	CWHdm	AR FH
1211	Inverness	54°12'	130°15'	17	CWHvh2	AR
1212	Haney	49°14'	122°36'	150	CWHdm	AR
1213	Big Qualicum River	49°24'	124°37'	5	CDFmm	AR
1214	Cedarvale	55°01'	128°19'	240	ICHmc2	AR
1215	Haney	49°14'	122°36'	150	CWHdm	AR
1216	Zolzap Creek	55°09'	129°13'	15	ICHmc2	AR

Appendix 2A *Continued*

Registration No.	Source	Latitude (°N)	Longitude (°W)	Elevation (m)	BGC unit	Trials
1217	Big Qualicum River	49°24'	124°37'	5	CDFmm	AR
1218	Big Qualicum River	49°24'	124°37'	5	CDFmm	AR
1219	Big Qualicum River	49°24'	124°37'	5	CDFmm	AR
1220	Big Qualicum River	49°24'	124°37'	5	CDFmm	AR
1221	Hoquiam	47°05'	124°03'	5	na	AR
1222	Big Qualicum River	49°24'	124°37'	5	CDFmm	AR
1223	Big Qualicum River	49°24'	124°37'	5	CDFmm	AR
1224	Big Qualicum River	49°24'	124°37'	5	CDFmm	AR
1225	Big Qualicum River	49°24'	124°37'	5	CDFmm	AR
1226	Big Qualicum River	49°24'	124°37'	5	CDFmm	AR
1227	Kitwanga	55°10'	127°52'	660	ICHmc2	AR
1228	Kitwanga	55°10'	127°52'	660	ICHmc2	AR
1229	Big Qualicum River	49°24'	124°37'	5	CDFmm	AR
1230	Kitwanga	55°10'	127°52'	660	ICHmc2	AR
1231	Kitwanga	55°10'	127°52'	660	ICHmc2	AR
1232	Big Qualicum River	49°24'	124°37'	5	CDFmm	AR
1233	Big Qualicum River	49°24'	124°37'	5	CDFmm	AR
1234	Big Qualicum River	49°24'	124°37'	5	CDFmm	AR
1235	Big Qualicum River	49°24'	124°37'	5	CDFmm	AR
1236	Kitwanga	55°10'	127°52'	660	ICHmc2	AR
1237	Big Qualicum River	49°24'	124°37'	5	CDFmm	AR
1238	Usk Ferry	54°38'	128°24'	135	CWHws1	AR
1239	Big Qualicum River	49°24'	124°37'	5	CDFmm	AR
1240	Big Qualicum River	49°24'	124°37'	5	CDFmm	AR
1241	Big Qualicum River	49°24'	124°37'	5	CDFmm	AR
1242	Big Qualicum River	49°24'	124°37'	5	CDFmm	AR
1243	Big Qualicum River	49°24'	124°37'	5	CDFmm	AR
1244	Big Qualicum River	49°24'	124°37'	5	CDFmm	AR
1245	Big Qualicum River	49°24'	124°37'	5	CDFmm	AR
1246	Big Qualicum River	49°24'	124°37'	5	CDFmm	AR
1247	Kitwanga	55°10'	127°52'	660	ICHmc2	AR
1248	Kitwanga	55°10'	127°52'	660	ICHmc2	AR
1249	Kitwanga	55°10'	127°52'	660	ICHmc2	AR
1250	Haney	49°14'	122°36'	150	CWHdm	MB
1251	Haney	49°14'	122°36'	150	CWHdm	MB
1252	Haney	49°14'	122°36'	150	CWHdm	EC
1253	Haney	49°14'	122°36'	150	CWHdm	AR
1254	Fair Harbour	50°03'	127°02'	30	CWHvm1	MB
1255	Fair Harbour	50°03'	127°02'	30	CWHvm1	na
1256	Fair Harbour	50°03'	127°02'	30	CWHvm1	MB
1257	Fair Harbour	50°03'	127°02'	30	CWHvm1	MB
1259	Miracle Beach	49°50'	125°04'	5	CWHxm1	MB
1260	Miracle Beach	49°50'	125°04'	5	CWHxm1	MB
1261	Miracle Beach	49°50'	125°04'	5	CWHxm1	MB
1263	Miracle Beach	49°50'	125°04'	5	CWHxm1	MB
1264	Miracle Beach	49°50'	125°04'	5	CWHxm1	MB
1265	Miracle Beach	49°50'	125°04'	5	CWHxm1	MB
1266	Miracle Beach	49°50'	125°04'	5	CWHxm1	MB
1267	Miracle Beach	49°50'	125°04'	5	CWHxm1	MB
1268	Miracle Beach	49°50'	125°04'	5	CWHxm1	MB
1269	Miracle Beach	49°50'	125°04'	5	CWHxm1	EC
1270	Miracle Beach	49°50'	125°04'	5	CWHxm1	EC
1271	Miracle Beach	49°50'	125°04'	5	CWHxm1	MB
1272	Haney	49°14'	122°36'	150	CWHdm	EC
1359	Haney	49°14'	122°36'	150	CWHdm	EC
1360	Haney	49°14'	122°36'	150	CWHdm	EC

Appendix 2A ***Continued***

Registration No.	Source	Latitude (°N)	Longitude (°W)	Elevation (m)	BGC unit	Trials
1361	Cedarvale	55°01'	128°19'	240	ICHmc2	EC
1362	Cedarvale	55°01'	128°19'	240	ICHmc2	EC
1363	Cedarvale	55°01'	128°19'	240	ICHmc2	EC
1364	Cedarvale	55°01'	128°19'	240	ICHmc2	EC
1365	Kitwanga	55°10'	127°52'	660	ICHmc2	EC
1366	Kitwanga	55°10'	127°52'	660	ICHmc2	EC
1367	Kitwanga	55°10'	127°52'	660	ICHmc2	EC
1368	Kitwanga	55°10'	127°52'	660	ICHmc2	EC
1369	Aberdeen Creek	54°12'	129°55'	5	CWHvh2	EC

Trials: AR – Armishaw Road, EC – Espinosa Creek, FH – Fair Harbour, GR- Glenroy Road, MB-Menzies Bay, SC – Sandcut Creek (Appendix 1B EP 702.06)

APPENDIX 2B Source of Parent Trees: EP 702.08.01—Jordan River Series 1992

Registration No.	Source	Latitude (°N)	Longitude (°W)	Elevation (m)	BGC unit
965	Dungeness 1 Wash.	48°10'	123°15'	20	na
966	Dungeness 2 Wash.	48°10'	123°15'	20	na
967	Anderson Lake 3 Wash.	48°01'	122°48'	55	na
968	Anderson Lake 4 Wash.	48°01'	122°48'	55	na
969	Anderson Lake 4A Wash.	48°01'	122°48'	55	na
970	Anderson Lake 5 Wash.	48°01'	122°48'	55	na
971	Anderson Lake 6 Wash.	48°01'	122°48'	55	na
972	Anderson Lake 7 Wash.	48°01'	122°48'	55	na
973	Sequim Bay 8 Wash.	48°02'	123°00'	10	na
974	Sequim Bay 9 Wash.	48°02'	123°00'	10	na
975	Sequim Bay 10 Wash.	48°02'	123°00'	10	na
976	Sequim Bay 11 Wash.	48°02'	123°00'	10	na
977	Sequim Bay 12 Wash.	48°02'	123°00'	10	na
978	Sequim Bay 13 Wash.	48°02'	123°00'	10	na
979	Hood Canal 14 Wash.	47°52'	122°40'	80	na
980	Hood Canal 15 Wash.	47°52'	122°40'	80	na
981	Hood Canal 16 Wash.	47°52'	122°40'	80	na
982	Beaver Valley 21 Wash.	47°58'	122°46'	60	na
983	Beaver Valley 22 Wash.	47 °58'	122°46'	60	na
984	Beaver Valley 23 Wash.	47°58'	122°46'	60	na
985	Beaver Valley 24 Wash.	47°58'	122°46'	60	na
986	Beaver Valley 25 Wash.	47°58'	122°46'	60	na
987	Leland Valley 26 Wash.	47°55'	122°53'	40	na
988	Leland Valley 27 Wash.	47°55'	122°53'	40	na
989	Hamma Hamma 28 Wash.	47°32'	123°03'	1	na
990	Hamma Hamma 29 Wash.	47°32'	123°03'	1	na
991	Little Rock Road 30 Wash.	46°59'	122°57'	50	na
992	Little Rock Road 31 Wash.	46°59'	122°57'	50	na
993	Little Rock Road 32 Wash.	46°59'	122°57'	50	na
994	Toutle River 33 Wash.	46°19'	122°34'	700	na
995	Toutle River 34 Wash.	46°19'	122°34'	700	na
996	Pe Ell 35 Chehalis Wash.	46°32'	123°22'	300	na
997	Pe Ell 36 Chehalis Wash.	46°32'	123°22'	300	na
998	Pe Ell 37 Chehalis Wash.	46°32'	123°22'	300	na
999	Campbell River 1 BC	50°02'	125°15'	3	CWHxm1
1000	Campbell River 2 BC	50°02'	125°15'	3	CWHxm1

Appendix 2B *Continued*

Registration No.	Source	Latitude (°N)	Longitude (°W)	Elevation (m)	BGC unit
1001	Campbell River 3 BC	50°02'	125°15'	3	CWHxm1
1002	Campbell River 4 BC	50°02'	125°15'	3	CWHxm1
1003	Oyster Bay 1 BC	49°52'	125°09'	10	CWHxm1
1004	Oyster Bay 2 BC	49°52'	125°09'	10	CWHxm1
1005	Oyster Bay 3 BC	49°52'	125°09'	10	CWHxm1
1006	Comox 1 BC	49°44'	124°58'	20	CWHxm1
1007	Comox 2 BC	49°44'	124°58'	20	CWHxm1
1008	Comox 3 BC	49°44'	124°58'	20	CWHxm1
1009	Courtenay 1 BC	49°42'	125°00'	10	CWHxm1
1010	Courtenay 2 BC	49°42'	125°00'	10	CWHxm1
1011	Royston 1	49°37'	124°56'	20	CWHxm1
1012	Royston 2	49°37'	124°56'	20	CWHxm1
1013	Royston 3	49°37'	124°56'	20	CWHxm1
1014	Buckley Bay 1	49°31'	124°51'	5	CWHxm1
1015	Buckley Bay 2	49°31'	124°51'	5	CWHxm1
1016	Buckley Bay 3	49°31'	124°51'	5	CWHxm1
1017	Fanny Bay 2 BC	49°30'	124°49'	10	CWHxm1
1018	Fanny Bay 3 BC	49°30'	124°49'	10	CWHxm1
1019	Mud Bay 1 BC	49°28'	124°46'	5	CWHxm1
1020	Deep Bay 1 BC	49°27'	124°45'	5	CWHxm1
1021	Deep Bay 2 BC	49°27'	124°45'	5	CWHxm1
1022	Horne Lake 1 BC	49°23'	124°36'	10	CDFmm
1023	Qualicum Beach 1 BC	49°22'	124°29'	5	CDFmm
1024	Qualicum Beach 2 BC	49°22'	124°29'	5	CDFmm
1025	Qualicum Beach 3 BC	49°22'	124°29'	5	CDFmm
1026	Nanoose 1 BC	49°16'	124°12'	10	CDFmm
1027	Ladysmith 1 BC	49°02'	123°51'	10	CDFmm
1028	Ladysmith 2 BC	49°02'	123°51'	10	CDFmm
1029	Dougan Lake 1 BC	48°43'	123°37'	20	CDFmm
1030	Dougan Lake 2 BC	48°43'	123°37'	20	CDFmm
1031	Dougan Lake 3 BC	48°43'	123°37'	20	CDFmm
1032	Mill Bay 1 BC	48°39'	123°33'	20	CDFmm
1033	Gillies Bay 1 BC	49°41'	124°29'	10	CDFmm
1034	Gillies Bay 2 BC	49°41'	124°29'	10	CDFmm
1035	Gillies Bay 3 BC	49°41'	124°29'	10	CDFmm
1036	Gillies Bay 4 BC	49°41'	124°29'	10	CDFmm
981	Hood Canal 16 Wash.	47°52'	122°40'	80	na
91961	SL 1961 Fair Harbour	50°05'	127°00'	48	CWHvm1
91496	SL 1496 Opitsat	49°11'	125°50'	30	CWHvm1
92135	SL 2135 San Josef	50°40'	128°12'	40	CWHvh1
92262	SL 2262 Tlupana River	49°47'	126°20'	152	CWHvh1
97946	SL 7946 Necancium River	45°30'	124°00'	110	na
97948	SL 7948 Forks Wash.	48°10'	124°15'	10	na
90001	Skidegate Channel 1 (QCI)	53°08'	132°16'	70	CWHwh1
90002	Skidegate Channel 2 (QCI)	53°08'	132°16'	70	CWHwh1
90003	Tlell River 1 (QCI)	53°22'	131°55'	7	CWHwh1
90004	Tlell River 2 (QCI)	53°22'	131°55'	7	CWHwh1
90005	Copper Bay (QCI)	53°07'	131°41'	10	CWHwh1
90006	Masset (QCI)	54°04'	131°47'	1	CWHwh1
90007	Sleeping Beauty Mtn. (QCI)	53°15'	132°14'	650	CWHwh2

APPENDIX 2C Source of Parent Trees: EP 702.08.02—Port Renfrew Series 1994

Registration No.	Source	Latitude (°N)	Longitude (°W)	Elevation (m)	BGC unit
1190	Russian Gulch 1 Calif.	39°20′	123°48′	25	na
1191	Russian Gulch 2 Calif.	39°20′	123°48′	25	na
1192	Russian Gulch 3 Calif.	39°21′	123°48′	20	na
1195	Samoa 1 Calif.	40°49′	124°11′	10	na
1196	Trinidad 1 Calif.	41°08′	124°09′	40	na
1197	Trinidad 2 Calif.	41°08′	124°09′	35	na
1198	Trinidad 3 Calif.	41°08′	124°09′	40	na
1199	Trinidad 4 Calif.	41°08′	124°09′	30	na
1200	Price Creek 1 Calif.	40°31′	124°12′	120	na
1201	Price Creek 2 Calif.	40°31′	124°12′	120	na
1202	Price Creek 3 Calif.	40°31′	124°12′	110	na
1203	Price Creek 4 Calif.	40°33′	124°11′	45	na
1258	Miracle Beach 1	49°51′	125°06′	10	CWHxm1
1259	Miracle Beach 2	49°51′	125°06′	10	CWHxm1
1260	Miracle Beach 3	49°51′	125°06′	10	CWHxm1
1261	Miracle Beach 4	49°51′	125°06′	10	CWHxm1
1262	Miracle Beach 5	49°51′	125°06′	10	CWHxm1
1273	Amor de Cosmos 1	50°15′	125°40′	75	CWHxm2
1274	Amor de Cosmos 2	50°15′	125°39′	65	CWHxm2
1275	Amor de Cosmos 3	50°15′	125°39′	65	CWHxm2
1276	Amor de Cosmos 4	50°15′	125°39′	65	CWHxm2
1277	Amor de Cosmos 5	50°15′	125°39′	65	CWHxm2
1278	Salmon River 1	50°21′	125°55′	10	CWHxm2
1279	Salmon River 2	50°21′	125°55′	10	CWHxm2
1280	Salmon River 3	50°21′	125°55′	10	CWHxm2
1281	Salmon River 4	50°21′	125°55′	10	CWHxm2
1282	Salmon River 5	50°21′	125°55′	10	CWHxm2
1283	Salmon River 6	50°21′	125°55′	10	CWHxm2
1295	Hilliers 1	49°17′	124°28′	150	CWHxm1
1296	Hilliers 2	49°18′	124°30′	130	CDFmm
1297	Hilliers 3	49°18′	124°30′	130	CDFmm
1298	Hilliers 4	49°18′	124°30′	130	CDFmm
1299	Hilliers 6	49°18′	124°30′	130	CDFmm
1301	Beaver Creek 1	49°24′	124°57′	135	CWHxm2
1302	Beaver Creek 2	49°24′	124°59′	145	CWHxm2
1303	Beaver Creek 3	49°24′	124°57′	145	CWHxm2
1304	Beaver Creek 4	49°23′	124°59′	100	CWHxm2
1589	Burnaby Lake 1 BC	49°14′	122°56′	40	CWHdm
1733	Mud Bay 1 BC	49°29′	124°48′	5	CWHxm1
9001	Skidegate Channel 1 (QCI)	53°08′	132°16′	70	CWHwh1
9004	Tlell River 2 (QCI)	53°22′	131°55′	7	CWHwh1
9005	Copper Bay (QCI)	53°07′	131°41′	10	CWHwh1
9006	Masset (QCI)	54°04′	131°47′	1	CWHwh1
9007	Sleeping Beauty (QCI)	53°15′	132°14′	650	CWHwh2
9008	Garden Bay 1	49°40′	124°02′	5	CWHxm1
9009	Garden Bay 2	49°40′	124°02′	5	CWHxm1
9010	Garden Bay 3	49°40′	124°02′	5	CWHxm1
9011	Garden Bay 4	49°40′	124°02′	5	CWHxm1
9012	Garden Bay 5	49°40′	124°02′	5	CWHxm1
9013	Sechelt 1	49°30′	123°45′	10	CWHxm1
9014	Sechelt 2	49°30′	123°45′	10	CWHxm1
9015	Sechelt 4	49°30′	123°45′	10	CWHxm1
9016	Cranberry Lake 1 Wash.	48°25′	122°40′	5	na
9017	Cranberry Lake 2 Wash.	48°25′	122°40′	5	na
9018	Cranberry Lake 3 Wash.	48°25′	122°40′	5	na
9019	Cranberry Lake 4 Wash.	48°25′	122°40′	5	na

Appendix 2c ***Continued***

Registration No.	Source	Latitude (°N)	Longitude (°W)	Elevation (m)	BGC unit
9020	Cranberry Lake 5 Wash.	48°25'	122°40'	5	na
9021	Cranberry Lake 6 Wash.	48°25'	122°40'	5	na
9022	Cranberry Lake 7 Wash.	48°25'	122°40'	5	na
9023	South Whidbey 1 Wash.	48°25'	122°40'	5	na
9024	South Whidbey 3 Wash.	48°25'	122°40'	5	na
9025	Tulalip 1 Wash.	48°05'	122°15'	30	na
9026	Tulalip 3 Wash.	48°05'	122°15'	30	na
9027	Whidbey Island 1 Wash.	48°20'	122°40'	15	na
9028	Whidbey Island 2 Wash.	48°20'	122°40'	15	na
9029	Whidbey Island 3 Wash.	48°20'	122°40'	15	na
9030	Whidbey Island 4 Wash.	48°20'	122°40'	15	na
9031	Whidbey Island 5 Wash.	48°20'	122°40'	15	na
9032	Fort Ebey 1 Wash.	48°15'	122°45'	30	na
9033	Fort Ebey 2 Wash.	48°15'	122°45'	30	na
9056	Hilliers 5	49°18'	124°30'	130	CDFmm
9057	Hilliers 7	49°18'	124°30'	130	CDFmm
91394	Knight Inlet	50°50'	125°35'	400	CWHvm1
91496	Opitsat	49°11'	125°50'	30	CWHvm1
91850	Wesach Creek	54°49'	128°45'	330	CWHvh1
91961	SL 1961 Fair Harbour	50°05'	127°00'	46	CWHvm1
97948	SL 7948 Forks, Wash.	48°10'	124°15'	10	na

APPENDIX 2D Source of Parent Trees: EP 702.08.03—Camp 4 Series 1995

Registration No.	Source	Latitude (°N)	Longitude (°W)	Elevation (m)	BGC unit
1310	Tsawwassen 1	49°02'	123°06'	15	CDFmm
1311	Tsawwassen 2	49°02'	123°06'	15	CDFmm
1312	Tsawwassen 3	49°02'	123°06'	15	CDFmm
1313	Tsawwassen 4	49°02'	123°06'	15	CDFmm
1320	Campbell Valley 1	49°02'	122°39'	50	CDFmm
1321	Campbell Valley 2	49°02'	122°39'	50	CDFmm
1322	Campbell Valley 3	49°02'	122°39'	50	CDFmm
1327	Hatzic Slough 1	49°11'	122°16'	30	CWHdm
1328	Hatzic Slough 2	49°11'	122°16'	30	CWHdm
1329	Hatzic Slough 3	49°11'	122°16'	30	CWHdm
1330	Silverdale Creek 1	49°08'	122°21'	15	CWHdm
1331	Silverdale Creek 2	49°08'	122°21'	15	CWHdm
1332	Silverdale Creek 3	49°08'	122°21'	15	CWHdm
1333	Silverdale Creek 4	49°08'	122°21'	15	CWHdm
1334	Silverdale Creek 5	49°08'	122°21'	15	CWHdm
1335	Silverdale Creek 6	49°08'	122°21'	15	CWHdm
1445	Issaquah Wash.	47°33'	122°03'	80	na
1446	Falls City 1 Oreg.	47°31'	121°57'	105	na
1449	North Bend 1 Wash.	47°24'	121°44'	430	na
1450	North Bend 2 Wash.	47°24'	121°44'	430	na
1451	North Bend 3 Wash.	47°24'	121°44'	430	na
1453	North Bend 5 Wash.	47°24'	121°44'	430	na
1454	North Bend 6 Wash.	47°24'	121°44'	430	na
1457	White River 1 Wash.	47°11'	121°44'	520	na
1458	White River 2 Wash.	47°11'	121°44'	520	na
1459	White River 3 Wash.	47°11'	121°44'	520	na
1460	White River 4 Wash.	47°11'	121°44'	520	na

Appendix 2D *Continued*

Registration No.	Source	Latitude (°N)	Longitude (°W)	Elevation (m)	BGC unit
1489	Federation 1 Wash.	47°14′	121°47′	480	na
1490	Federation 2 Wash.	47°14′	121°47′	480	na
1491	Federation 3 Wash.	47°14′	121°47′	480	na
1492	Federation 4 Wash.	47°14′	121°47′	480	na
1493	Federation 5 Wash.	47°14′	121°47′	480	na
1549	Mud Bay	49°05′	122°52′	5	CWHxm1
1582	Pitt Meadows 1	49°13′	122°45′	25	CWHdm
1583	Pitt Meadows 2	49°13′	122°45′	25	CWHdm
1584	Pitt Meadows 3	49°13′	122°45′	25	CWHdm
1585	Pitt Meadows 4	49°13′	122°45′	25	CWHdm
1586	Pitt Meadows 5	49°13′	122°45′	25	CWHdm
1587	Bayliss 1	49°15′	122°55′	45	CWHdm
1588	Bayliss 2	49°15′	122°55′	45	CWHdm
1592	Seymour River 1	49°24′	123°59′	140	CWHvm1
1593	Seymour River 2	49°24′	123°59′	140	CWHvm1
1594	Seymour River 3	49°24′	123°59′	140	CWHvm1
1595	Seymour River 4	49°24′	123°59′	140	CWHvm1
1596	Butler 1	48°14′	123°26′	55	CDFmm
1597	Butler 2	48°14′	123°26′	55	CDFmm
1598	Butler 3	48°14′	123°26′	55	CDFmm
9001	Skidegate Channel 1 (QCI)	53°08′	132°16′	70	CWHwh1
9003	Tlell River 1 (QCI)	53°22′	131°55′	7	CWHwh1
9005	Copper Bay (QCI)	53°07′	131°41′	10	CWHwh1
9006	Massett (QCI)	54°04′	131°47′	1	CWHwh1
9007	Sleeping Beauty (QCI)	53°15′	132°14′	650	MHwh2
9034	Sechelt 22	49°30′	123°45′	10	CWHxm1
9035	Sechelt 23	49°30′	123°45′	10	CWHxm1
9036	Telegraph Creek 1 Alaska	57°49′	131°24′	160	SBSun
9037	Telegraph Creek 2 Alaska	57°49′	131°24′	160	SBSun
9038	Telegraph Creek 4 Alaska	57°49′	131°24′	160	SBSun
9039	Rainier 1 Wash.	46°04′	123°32′	20	na
9040	Rainier 4 Wash.	46°04′	123°32′	20	na
9041	Clatsop 1 Oreg.	46°12′	123°32′	20	na
9042	Clatsop 2 Oreg.	46°12′	123°32′	20	na
9043	Clatsop 6 Oreg.	46°12′	123°32′	20	na
9044	Clatsop 7 Oreg.	46°12′	123°32′	20	na
9045	Florence 2 Oreg.	44°00′	124°00′	15	na
9046	Florence 5 Oreg.	44°00′	124°00′	15	na
9047	Florence 8 Oreg.	44°00′	124°00′	15	na
9048	Florence 9 Oreg.	44°00′	124°00′	15	na
9049	Bandon 1 Oreg.	43°07′	124°24′	30	na
9050	Bandon 5 Oreg.	43°07′	124°24′	30	na
9051	Coquille 5 Oreg.	43°06′	124°19′	70	na
9052	Coquille 6 Oreg.	43°06′	124°19′	70	na
9053	Brookings 3 Oreg.	42°03′	124°19′	40	na
9054	Brookings 4 Oreg.	42°03′	124°19′	40	na
9055	Lone Ranch 4 Oreg.	42°08′	124°21′	35	na
9438	SL 40438 Pigott Q	49°19′	124°25′	75	CDFmm
9439	SL 40439 Pigott M	49°50′	125°04′	50	CWHxm1
9449	SL 40449 Pigott C	49°17′	124°25′	180	CDFmm
91394	SL 1394 Knight Inlet	50°50′	125°35′	400	CWHvm1
91496	SL 1496 Opitsat	49°11′	125°50′	30	CWHvm1
91850	SL 1850 Wesach Creek	54°49′	128°45′	330	CWHvh1
91961	SL 1961 Fair Harbour	50°05′	127°00′	48	CWHvm1
92135	SL 2135 San Josef	50°40′	128°12′	40	CWHvh1
92262	SL 2262 Tlupana River	49°47′	126°20′	152	CWHvm1

APPENDIX 2E Source of Parent Trees: EP 702.08.04—Coombs Series 1999

Registration No.	Source	Latitude (°N)	Longitude (°W)	Elevation (m)	BGC unit
1017	Fanny Bay 2	49°30'	124°49'	10	CWHxm1
1018	Fanny Bay 3	49°30'	124°49'	10	CWHxm1
1024	Qualicum Beach 2	49°21'	124°29'	5	CDFmm
1314	White Rock 1	49°04'	122°48'	15	CWHxm1
1315	White Rock 2	49°04'	122°48'	15	CWHxm1
1317	White Rock 4	49°04'	122°49'	10	CWHxm1
1318	White Rock 5	49°04'	122°49'	10	CWHxm1
1319	White Rock 6	49°04'	122°49'	10	CWHxm1
1323	Aldergrove Lake 1	40°01'	122°28'	50	CWHxm1
1324	Aldergrove Lake 2	49°01'	122°28'	50	CWHxm1
1325	Aldergrove Lake 3	49°01'	122°28'	50	CWHxm1
1326	Aldergrove Lake 4	49°01'	122°28'	50	CWHxm1
1336	Stave River 1	49°11'	122°35'	25	CWHdm
1337	Stave River 2	49°11'	122°35'	25	CWHdm
1338	Stave River 3	49°11'	122°35'	25	CWHdm
1339	Albion I.R. 1	49°11'	122°35'	10	CWHxm1
1340	Albion I.R. 2	49°11'	122°35'	10	CWHxm1
1341	Albion I.R. 3	49°11'	122°35'	10	CWHxm1
1342	Albion I.R. 4	49°11'	122°35'	10	CWHxm1
1500	Little Qualicum Falls 1	49°19'	124°33'	135	CWHxm1
1501	Royston Rd 1	49°38'	124°57'	60	CWHxm1
1503	Royston Rd. 3	49°38'	124°59'	110	CWHxm1
1506	Little Qualicum Hatchery 2	49°21'	124°30'	15	CDFmm
1507	Little Qualicum Hatchery 3	49°21'	124°30'	15	CDFmm
1510	Little Qualicum Hatchery 6	49°21'	124°31'	20	CDFmm
1511	Camp-4 1	50°05'	125°22'	80	CWHxm1
1514	Little Qualicum Falls 2	49°19'	124°32'	130	CDFmm
1515	Little Qualicum Falls 3	49°19'	124°32'	125	CDFmm
1575	Coleman 1	49°10'	122°16'	65	CWHdm
1576	Coleman 2	49°10'	122°16'	65	CWHdm
1577	Coleman 3	49°10'	122°18'	150	CWHdm
1582	Pitt Meadows 1	49°12'	122°40'	5	CWHdm
1583	Pitt Meadows 2	49°12'	122°40'	5	CWHdm
1584	Pitt Meadows 3	49°12'	122°40'	5	CWHdm
1589	Burnaby Lake 1	49°15'	122°56'	15	CWHdm
1590	Burnaby Lake 2	49°15'	122°56'	15	CWHdm
1591	Burnaby Lake 3	49°15'	122°56'	15	CWHdm
1627	Royston 37	49°37'	124°55'	50	CWHxm1
1629	Rosewall Creek 17	49°27'	124°43'	10	CWHxm1
1631	Buckley Bay 5	49°31'	124°50'	5	CWHxm1
1633	Rosewall Creek 14	49°27'	124°48'	5	CWHxm1
1634	Ships Point 3	49°30'	124°48'	10	CWHxm1
1635	Horne Lake 35	49°20'	124°44'	125	CWHxm1
1637	Deep Bay School 21	49°27'	124°42'	75	CDFmm
1639	Little Qualicum River 30	49°21'	124°29'	5	CDFmm
1640	Mud Bay 3	49°27'	124°47'	5	CWHxm1
1641	Big Qualicum River 24	49°24'	124°37'	10	CDFmm
1645	Rosewall Creek 18	49°27'	124°45'	10	CWHxm1
1646	Deep Bay School 19	49°27'	124°42'	70	CDFmm
1648	Comox 40	49°44'	124°56'	50	CWHxm1
1649	Big Qualicum River 28	49°25'	125°37'	20	CDFmm
1652	Big Qualicum River 25	49°24'	124°37'	20	CDFmm
1654	Ships Point 1	49°30'	124°48'	10	CWHxm1
1655	Mud Bay 2	49°28'	124°47'	5	CWHxm1
1656	Buckley Bay 4	49°31'	124°51'	5	CWHxm1
1659	Deep Bay 3	[illegible]	124°46'	5	CWHxm1

Appendix 2E ***Continued***

Registration No.	Source	Latitude (°N)	Longitude (°W)	Elevation (m)	BGC unit
1701	Qualicum 1 (Old Hilliers)	49°20′	124°27′	88	CDFmm
1702	Qualicum 2 (Old Hilliers)	49°20′	124°27′	88	CDFmm
1703	Qualicum 3 (1996)	49°19′	124°27′	105	CDFmm
1704	Coombs 4 (1996)	49°18′	124°29′	160	CDFmm
1705	Tsable River 5	49°31′	124°50′	90	CWHxm1
1706	Waveland 1	49°45′	124°56′	30	CWHxm1
1707	Farnham Road 4	49°46′	125°07′	70	CWHxm1
1708	Puntledge River 6	49°40′	125°03′	85	CWHxm1
1709	Puntledge River 7	49°40′	125°03′	80	CWHxm1
1710	Lake Trail Road 8	49°40′	125°03′	80	CWHxm1
1711	Burns Road 9	49°43′	125°04′	80	CWHxm1
1712	Johnson Road 10	49°41′	125°10′	425	CWHxm1
1713	Deep Bay 6 (1996)	49°28′	124°42′	70	CWHxm1
1714	Deep Bay 7 (1996)	49°27′	124°42′	70	CWHxm1
1715	Qualicum 1 (Fish Plant)	49°24′	124°37′	10	CDFmm
1716	Qualicum 2 (Fish Plant)	49°24′	124°37′	10	CDFmm
1717	Qualicum 3 (McColl Rd)	49°25′	124°40′	55	CDFmm
1718	Qualicum 4 (McColl Rd)	49°25′	124°40′	55	CDFmm
1719	Qualicum 5 (Cochrane Rd)	49°24′	124°37′	10	CDFmm
1720	Qualicum 6 (Cochrane Rd))	49°24′	124°37′	10	CDFmm
1721	Qualicum 7 (Cochrane Rd)	49°24′	124°37′	10	CDFmm
1722	Qualicum 8 (Cochrane Rd)	49°24′	124°37′	10	CDFmm
1723	Qualicum 9 (Hatchery))	49°24′	124°37′	18	CDFmm
1724	Qualicum 10 (Hatchery)	49°23′	124°37′	20	CDFmm
1725	Qualicum Band office 11	49°23′	124°37′	35	CDFmm
1726	Big Qualicum River 26	49°23′	124°37′	15	CDFmm
9003	Tlell 1 (QCI)	53°22′	131°55′	7	CWHwh1
9004	Tlell 2 (QCI)	53°22′	131°55′	7	CWHwh1
9005	Copper Bay (QCI)	53°07′	131°41′	10	CWHwh1
9006	Masset (QCI)	54°04′	131°47′	1	CWHwh1
9007	Sleeping Beauty (QCI)	53°15′	132°14′	650	CWHwh2
9058	Oregon Dep. For. 1	na	na	na	na
9059	Oregon Dep. For. 2	na	na	na	na
9060	Oregon Dep. For. 3	na	na	na	na
9061	Oregon Dep. For. 4	na	na	na	na
9062	Oregon Dep. For. 5	na	na	na	na
9063	Oregon Dep. For. 6	na	na	na	na
9064	Oregon Dep. For. 7	na	na	na	na
9065	Oregon Dep. For. 8	na	na	na	na
9066	Oregon Dep. For. 9	na	na	na	na
9067	Oregon Dep. For. 10	na	na	na	na
9068	Oregon Dep. For. 11	na	na	na	na
9069	Oregon Dep. For. 12	na	na	na	na
9070	Oregon Dep. For. 13	na	na	na	na
9071	Oregon Dep. For. 14	na	na	na	na
9072	Oregon Dep. For. 15	na	na	na	na
9073	Oregon Dep. For. 16	na	na	na	na
9074	Oregon Dep. For. 17	na	na	na	na
9075	Oregon Dep. For. 18	na	na	na	na
9076	Oregon Dep. For. 19	na	na	na	na
9077	Oregon Dep. For. 20	na	na	na	na
9078	DNR Julia Bay 1	na	na	na	na
9079	DNR Julia Bay 2	na	na	na	na
9080	DNR Julia Bay 3	na	na	na	na
9081	DNR Julia Bay 4	na	na	na	na
9082	DNR Falls Creek 1	na	na	na	na

Appendix 2E ***Continued***

Registration No.	Source	Latitude (°N)	Longitude (°W)	Elevation (m)	BGC unit
9083	DNR Falls Creek 2	na	na	na	na
9084	DNR Falls Creek 3	na	na	na	na
9085	DNR Falls Creek 4	na	na	na	na
9086	DNR Falls Creek 5	na	na	na	na
9087	DNR Falls Creek 6	na	na	na	na
9088	DNR Ballock	na	na	na	na
9089	DNR Seago	na	na	na	na
9090	DNR Seattle	na	na	na	na
9091	Qualicum Standard	49°22'	124°36'	25	CDFmm
9092	Kumdis Standard	53°41'	132°09'	15	CWHwh1
91961	SL 1961 Fair Harbour	50°05'	127°00'	48	CWHvm1
92135	SL 2135 San Josef River	50°40'	128°12'	40	CWHvh1
92262	SL 2262 Tlupana River	49°47'	126°20'	152	CWHvm1
97946	SL 7946 Necanicumo R	45°30'	124°00'	110	na
97948	SL 7948 Forks Wash.	48°10'	124°15'	10	na

APPENDIX 3 Population Resistance Values from Provenance Trials

Provenance	Mean annual attack	SE[a]	Families tested	Latitude (°N)	Longitude (°W)	Elevation (m)	BGC unit
Alberni	23%	7%	4	49°24'	124°57'	135	CWHxm2
Albion	23%	6%	4	49°10'	122°34'	10	CWHxm1
Aldergrove	18%	5%	4	49°00'	122°27'	50	CWHxm1
Amor de Cosmos	39%	8%	4	50°15'	125°40'	75	CWHxm2
Bandon, Oreg.	56%	9%	4	43°07'	124°24'	30	na
Bayliss	15%	5%	2	49°15'	122°55'	45	CWHdm
Brooking, Oreg.	57%	10%	3	42°03'	124°19'	40	na
Burnaby Lake	24%	6%	4	49°14'	122°56'	15	CWHdm
Campbell River	18%	6%	6	50°02'	125°15'	3	CWHxm1
Campbell Valley	24%	7%	3	49°02'	122°39'	50	CDFmm
Clatsop, Oreg.	44%	8%	6	46°12'	123°32'	20	na
Comox	15%	4%	20	49°44'	124°56'	50	CWHxm1
Coombs	16%	4%	20	49°17'	124°29'	160	CDFmm
Dougan Lake	37%	9%	4	48°43'	123°37'	20	CWHxm2
Fanny Bay	21%	5%	20	49°29'	124°49'	10	CWHxm1
Federation, Wash.	33%	7%	5	47°14'	121°47'	480	na
Florence, Oreg.	49%	9%	4	44°00'	124°00'	15	na
Garden Bay	23%	6%	5	49°40'	124°02'	5	CWHxm1
Hamma Hamma, Wash.	31%	10%	2	47°32'	123°03'	1	na
Hatzic	16%	5%	5	49°10'	122°16'	65	CWHdm
Hatzic Slough	22%	6%	4	49°11'	122°16'	20	CWHdm
Hood Canal, Oreg.	37%	7%	10	47°52'	122°40'	80	na
Horne Lake	33%	8%	5	49°23'	124°36'	10	CWHxm1
Issaquah, Wash.	28%	8%	2	47°33'	122°03'	80	na
Jewel, Oreg.	45%	7%	8	45°56'	123°30'	100	na
Miracle Beach	23%	6%	20	49°50'	125°04'	50	CWHxm1
Nanoose	18%	7%	3	49°16'	124°12'	10	CWHxm1
North Bend, Wash.	36%	8%	4	47°24'	121°44'	430	na
Oyster Bay	29%	9%	4	49°52'	125°09'	10	CWHxm2
Pe Ell, Wash.	37%	9%	3	46°32'	123°22'	300	na
Pitt Meadows	22%	5%	8	49°13'	122°45'	25	CWHdm
Queen Charlotte Is.	48%	7%	5	53°22'	131°55'	7	CWHwh1
Qualicum	23%	5%	20	49°23'	124°37'	10	CDFmm
Saanich	38%	9%	3	48°34'	123°26'	55	CDFmm
Salmon River	48%	8%	6	50°21'	125°55'	10	CWHxm2
Seattle, Wash.	39%	8%	4	46°22'	123°04'	100	na
Sechelt	32%	7%	5	49°30'	123°45'	10	CDFmm
Sequim, Wash.	43%	8%	7	48°02'	123°00'	10	na
Seymour River	35%	8%	4	49°24'	123°59'	140	CWHvm1
Silverdale Creek	24%	6%	6	49°08'	122°21'	15	CWHdm
Stave River	18%	5%	4	49°10'	122°24'	25	CWHdm
Texada Island	23%	7%	4	49°41'	124°29'	10	CWHxm1
Tsawwassen	26%	7%	4	49°02'	123°06'	15	CDFmm
Tulalip, Wash.	42%	9%	2	48°05'	122°15'	30	na
Wahkiakum, Wash.	41%	7%	10	46°22'	123°04'	100	na
Whidbey Isl., Wash.	44%	7%	16	48°25'	122°40'	5	na
White River, Wash.	26%	7%	4	47°11'	121°44'	520	na
White Rock	33%	7%	4	49°04'	122°48'	15	CWHxm1
W. Vancouver Island	40%	7%	20	49°47'	126°20'	152	CWHvm1
Western Washington	44%	9%	20	48°10'	124°15'	10	na

a Standard error